A FRAMEWORK FOR DEVELOPING 4D LOD ON CONSTRUCTION PROJECTS

BOGDAN BUTKOVIC

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BOGDAN BUTKOVIC BSc (Hons) MSc

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This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purpose of assessment, publication or for any other purpose. Save for any express acknowledgments, references and or bibliographies cited in this work. I confirm that the intellectual content of the work is the result of my own efforts and no other person.

Signature…………………………………………………..

Date……**10th November 2019**……………………………………………..

To My Dear Parents,

Great thanks to God for giving me the gift for being your son.

“If you are working on something exciting that you really care about you don’t have to be **pushed**.

The vision **pulls** you.”

- Steve Jobs

Abstract

The increasing application of BIM processes and technologies has facilitated an increase in the use of 4D (3D+Time) simulations of construction projects. Numerous studies have acknowledged the benefit of 4D models in project planning and construction phases, enhancing communication between construction teams and avoiding unforeseen conflicts during the build process. The development of BIM has prompted a deeper understanding of the issue surrounding Level of Development (LODt), Level of Information (LOI) and Level of Detail (LOD) relating to the graphical detail and non-graphical information of the static geometric design model. However, up to now there is limited research methodically investigating the issue of LOD within 4D BIM applications.

This research aims to develop a framework for specifying the LOD of 4D BIM to enhance communication and planning at various stages of the construction process. A 4D simulation needs more dynamic elements to alter the current 4D static image in order to provide more realistic simulation and more accurate results.

A mixed research methods approach was developed to address the needs for successful framework development. A combination quantitative and qualitative survey was undertaken to gather data from professionals engaged in the development of 4D BIM simulations on construction projects. A framework was developed to provide professionals with an approach to develop LOD for 4D simulations (LOD_{4d}) and following this the framework was validated through qualitative interview with experts in the field. The uniqueness of the work required the invention of new terminology. The developed framework incorporates terms for Level of Graphical Detail (LOD_{g}) the graphical information of the model. Level of Detail of object geometry “granulated” (LOD_{gran}) into segments showing how the object was constructed over the time. The framework comprises a time period required between state changes in the model during the simulation which is Temporal Level of Detail (LOD_{ti}).

The outcome of the work is the generation of a framework which supports the development of 4D simulations at a range of LOD. This can then be utilised as part of the BIM process to support the generation of 4D simulations at levels of detail suitable to the operations being undertaken. This could then lead to the development of an additional protocol within the BIM suite. Beside the construction industry specialists have provided suggestions to further support approach of communication during the construction process.

Acknowledgments

I would like to give my deepest gratefulness to the people who contributed to the completion of the project.

I am forever thankful to my family for their unconditional love and understanding. To my parents, thank you both for your endless support, I dedicate this thesis to you.

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Glossary

3D	3-dimensional; shows a virtual model of the building element in the construction.
4D	4-dimensional; 3D plus time in the construction activity schedule.
AIA	American Institution of Architects is a professional institution of architects in the United States (US).
AIA E202	The Building Information Modeling Protocol Exhibit Document developed by AIA.
EIR	The Employer's Information Requirement is a part of the contract document that keeps the information required by the employer, for the procurement of the Design Team and Constructor. The document also includes the information required for the smoothly run of the project.
BEP	BIM Execution Plan is a clarification of roles and employers' responsibilities, standards to be applied, and processes to be followed and how the information modelling characteristics of a project will be executed.
BIM	Building Information Modelling is a set of processes for creating and managing information on a construction project throughout the project lifecycle.
BIM LOD	BIM Level of Development is a concept that defines the content and consistency of BIM elements at different phases of the construction project.

IFC	Industry Foundation Classes indicates an object-based file format established by buildingSMART includes detached and abstract building components.
LOD_{4d}	LOD of a 4D simulation is a unification of LOD_g and LOD_{ti} which details the time required in the simulation between state changes.
LOD	Level of Detail is the main stage of information; the model must include the different phases of a project lifecycle according to its use. LOD purpose is to model an object with the most appropriate geometry and representation agreed with a specific objective of analysis. LOD essentially defines model evolution.
LOD_g	Level of Graphical Detail is the geometry (graphical) information of the model during the course of the construction project.
LOD_{gran}	Level of Detail of object geometry “granulated” (divided into smaller segments to provide more dynamic 4D simulation).
LODt	Level of Development includes geometry and non-graphical information. From LOD 100 to LOD 500, the clear development for the geometric representation, probable prevision and presence of related data is defined. Essentially the standard classifies the level of development.
LOD_{ti}	Temporal Level of Detail is the non-graphical level of information during the construction project. It is the time period required between state changes in the model during the simulation.
LOI	Level of Information considers a quality of semantic parts of an object.

MPDT	Model Production Delivery Table is in the appendix to the Construction Industry Council's (CIC) BIM Protocol.
NBS	National Building Specification is a UK company of construction information management products from contract administrations to the AEC industry.
PAS	Publicly Available Specification is a document issued by British Standards Institution (BSI). The document is similar to a formal standard document from the UK government but has a different development model. The purpose of the document is to speed up standardization.
PAS1192	PAS1192 is a BSI group publication to provide the documentation for following the specification from the UK government.
PBS	Product Breakdown Structure is subdividing projects into product components.
UK BIM Level 2	To clearly define what, when and how information for any construction project should be created, managed and shared. BIM protocol needs to be followed in a pre-construction, construction, cooperative work which means to share data and work on one model. At Level 2, COBie (Construction Operations Building Information Exchange) is used and it is usually represented as a central spreadsheet where non-graphical data can be stored, shared and updated throughout the whole of the construction project.
WBS	Work Breakdown Structure is a decomposition of the work to be completed by the project team.

Chapter 1: Introduction

1.1 General Background

Technology plays an important role in construction projects helping to complete projects with a low cost and improving the relationship between the owner and the contractor by boosting their communications. With emerging technology, the very act of designing changed from 2D drawings to 3D digital models. These 3D digital models are assembled in the same way as a building is constructed.

All the parties included in the building process, the owner, architect, contractor, engineer, material suppliers and other roles pass the building model from one industry to another in order to achieve better input and successful outcomes. By using virtual reality applications, the 3D building model could be spontaneously manipulated and collaboratively used in different phases of building construction.

The 3D models were linked to time parameters and created four dimensional (4D) models (Fischer and Kunz, 2004). A 4D model improves construction projects by providing better communications among project parties (Leinonen *et al*., 2003) as well as improving the design, coordination, and construction process. Integrated with BIM, 4D modelling improves data integration even further.

However, a construction study by Poirier *et al.* (2015) highlighted that BIM is mainly used for the visualization, clash detection and building design, which indicates that beneficial BIM capabilities for pre-construction and prefabrication are being neglected. Limiting the use of BIM in the planning, field applications and site work demonstrates a knowledge gap in the AEC industry (Poirier *et al.*, 2015).

1.1.1 Background the research

Increasing interest in the collaborative use of 4D BIM modelling and simulation enhances the importance of the Level of Detail (LOD) of the model. The LOD model is affected by the time planned to build it and the size of the model and these important items need to be communicated. An architect’s standards and norms are different to a contractor’s standards and norms. The importance of items is not the same for an architect as it is for a contractor. For an example, the architect would highly detail a wall system with several components in order to support rendering for different materials. For a wall system, the contractor may choose to use a single component because the sequencing of wall sections and floors are more important to him. If the sequencing of detailed components is used, this requires a more detailed model for the installation of each step (Kensek, 2014, pp.159-160a).

Furthermore, the construction task might require several activities in order to build a single object. In this case, planners can apply multiple activities to a single component and to show formwork, concrete pour or wall finishes a single wall section can be used all over again (Eastman *et al.*, 2011, pp.286-7).

Communication between numerous participants is essential on collaborative projects, because the various design stages of the architectural process involve the collaboration of many disciplines. The design information that is generated in the early stages of a construction project is utilized and modified in the follow up stages. Thus, systematic management is required in all the construction stages (Choi *et al.*, 2014).

This study focuses on the importance of the four dimensional level of detail (LOD) on communication in different stages of the construction project. It addresses the depth of analyses and limitations in current collaboration and communication workflow in 4D technology.

1.2 Current status of research and practice

Considering the benefit of 4D modelling and simulation, the latest studies show advantages for 4D technology users as well as these modern technology limitations. Current research and practices reveal that miscommunication of the project information are the cause of two thirds of the problems arising in the construction industry planning and execution. The information in BIM incorporates space constraints, design information, cost, materials and manufacturing information, time, as well as information-based real-time collaboration.

The potential of working with a 4D BIM are huge and provide better management and better outcomes. However, the recent research shows that 4D tools used to support the collaborative activities are at a low level. The expectations of such tools are for it to be possible to make the use of visualization techniques adapted to all teams involved in the project. The visualized communication allows planners to plan needed work in the context of time and space, meaning that effective communication impacts the progress of projects.

Furthermore, the importance of regular scheduling of construction sequences need to be determined from the beginning of the design phase to the overall project.

The idea of this research is to explore the possibility to improving the 4D BIM model by specifying the 4D BIM level of detail which would help to overcome its limitations on the visualization issue.

1.2.1 Research Questions

The research identified communication issues are affected by LOD and they have to be resolved in order to produce more realistic simulations and prevent additional expenses and confusion among project team members.

There are many questions to be addressed before the construction project starts such as can MEP engineers use the architect's model for energy analysis or will the builder use discipline specific models for the construction coordination (Kensek, 2014, pp.159-160b).

A 4D CAD simulation requires two levels of detail during the creation process. There is a high level of detail in the graphical representation of the building product and when incorporating a 4D CAD in the analysis of the construction process, it is important to retain the low level of the graphical detail (Heesom, 2004a). When it comes to analysing the construction process, it is important that a sufficiently simplistic graphical representation of building products is used to portray the relationship between the 3D objects. Full photo realism is believed not to be able to provide information that can benefit the process. However, careful attention needs to be paid to the time delay during the visualization process within a 4D CAD simulation which adds an even further level of detail (Heesom, 2006a).

According to Kensek, levels of detail differ from one industry to another and therefore it creates a modelling issue. For that reason, it is crucial for an architect and contractor to agree on LOD-based milestone definitions and to clearly define the accuracy of used components and communicate intended uses of the model (Kensek, 2014, pp.167-168).

Most resent research on the adaption of 4D BIM by Gledson (2017) discussed the recognition of the 4D BIM simulation potentials and concern that 4D BIM has a very low adoption rate in the industry. The study offers the innovation-decision process model to contribute in making decisions for acceptance or rejection of such modular technical process-based innovations. Furthermore, the research debate that capturing actual task duration would increase organizational knowledge, which would lead in the future organizational planning quality and accurate project durations (Gledson, 2017).

The above studies consider the need of high and the low level of detail in the construction schedule sequencing as well as the apprehending actual task duration. However, there is no study focused on specifying the LOD for 4D. Graphical LOD is the geometrical precision of the 3D components and Temporal LOD, the non-graphical information, details the time required in the simulation between state changes.

The one single temporal LOD used throughout the project for simulation makes 4D simulation results not reliable as the model need to be constantly evaluated and updated as long as project develops. The research specifically investigated the influence of level of graphical and temporal detail on 4D simulation. This study attempted to answer the research question which methodology can unify Level of Graphical Detail (LOD_g) and the Level of Temporal Detail (LOD_{ti}) to deliver the requirement of the 4D LOD.

1.3 Aim and Objectives

Based on the foregoing, the aim of this project is the development of a Level of Detail (LOD) framework for 4D BIM to improve simulations at various stages of the construction process.

Based on the foregoing, the objectives of the study are:

1. Undertake a critical review of prevailing literature in the field of BIM and specifically the field of 4D modelling.
2. Investigating prevailing 4D software tools used for schedule visualization in construction engineering, specifically the technical capabilities and LOD approaches.
3. To deeper explore issues around 4D use and the issue of Level of Detail within 4D in practice to bring out the knowledge.
4. Development of a framework for the implementation and application of LOD within 4D simulations.
5. Validation of the framework via qualitative based interviews with construction professionals.

1.4 Research program

In order to succeed in gaining the desired results for the stated aim and objectives, the steps were conducted as follows:

- **Phase 1: Literature Review –** Investigation and analysis of the current knowledge including substantial findings about Building Information Modelling and value of existing 4D modelling tools.
- **Phase 2: Conceptual Framework development –** Real-time research within the industry investigating the current level of detail of available tools and fully understand the process of BIM in the real-time project. Analyse the communication plan based on the framework. Investigating the communication process in communication planning in the real-time project considering:
    - Who is involved in the construction project – identifying internal and external stakeholders, project team members and project managers and staff.
    - The communicated information between design and construction teams showing 4D model and model data exchange protocols.
    - How often the information is communicated – daily, weekly, monthly, as needed or as identified.
- **Phase 3: Questionnaire development and structure:**
    - **Case Study –** Development of the questionnaire for the industry participants and based on the real-time communication plan in live construction BIM projects.
    - **System Development –** The questionnaire structure, scheme and distribution to be in synchronization with the findings in the literature considering the communication at various stages in real-time construction projects, the industry needs, level of BIM used in practice and usage of 4D BIM.
- **Phase 4: Survey, Validation and Evaluation**
    - **Survey analyses –** Use of Statistical Package for the Social Science (SPSS) software to manage large volume of data.
    - **Validation protocol –** The framework validation confirms the credibility and the strength of a research study. Data collected and data analysed provides the data validity and data relatability.

- **Evaluation protocol –** Assessing the research objectives against the work completed. The assessment includes; evaluation of the developed LOD tracked information at a project level in different project stages. Review of collaboration and digital communication between design and construction team during all project phases.

1.5 Organization of study

The study comprises of eight chapters. The outline of the study is illustrated in Figure 1.2.

Chapter 1 provides a background of the study and motivation for the research study, its aim and objectives and introduces the research program.

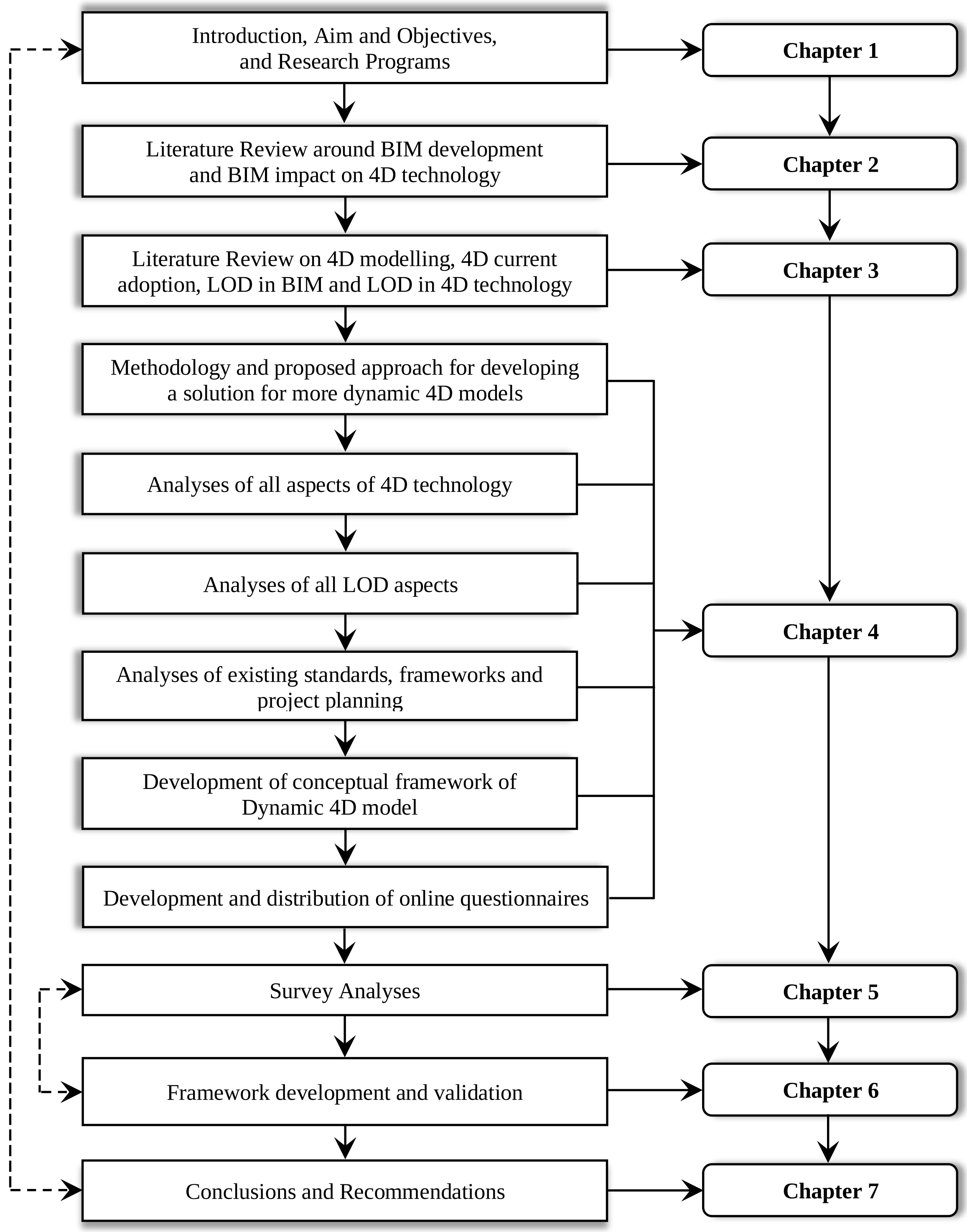

Figure 1.1: Organization of study

Chapter 2 underlines BIM development, BIM use and implementation. This chapter presents findings of BIM impact on 4D technology, this technology effect on project planning, introduces dimensions of BIM and give critical analyses of BIM advantages and disadvantages.

Chapter 3 presents the literature review of 4D modelling development, its current applications, its importance in project lifecycle and technologies' advantages and disadvantages. The chapter also provides the literature on Industry Foundation Classes and its role in 4D technology. The chapter outlines the roll of the level of detail in BIM and in 4D technology. The chapter provides an insight of the importance of the Graphical level of detail and the Temporal level of detail.

Chapter 4 draws attention to the reasoning behind research methodology in this project based on the literature review and summarizing the analyses of all aspects of 4D technology and LOD. Based on the literature review and analyses the conceptual framework for more dynamic 4D model was developed. In this chapter the research methodology of the survey questionnaire was introduced in order to ensure the opinions of professional users from the industry and therefore develop deeper knowledge of the requirements of more dynamic 4D simulations.

Chapter 5 presents results, analyses and discusses gathered data of the user evaluation questionnaire. The questionnaire included questions of demographic information on the responder, sector of company, role of the participants and results around the use of 4D, the role of BIM in the company and the technology used for a 4D simulation.

Chapter 6 provides details of the final development, framework application and the framework validation.

In Chapter 7, conclusions were given, the recommendations for future research and recommendation for industry practices.

Chapter 2: Literature Review

2.1 Introduction

In the current AEC industry, many essays explore 4D BIM's potential for an architectural design. All the authors provide insights and evaluation of current practice and research directions of 4D BIM. However, there is an area which is not explored in an adequate amount although it would help to improve the planning design process and overall construction project. Such an area that needs more understanding is 4D BIM level of detail.

This chapter is a review of the literature showing the development of BIM and a discussion of different details of BIM indicating the importance of this technology in the AEC industry. In order to seek proper approaches and understanding of the need for this research, this chapter provides a broader discussion regarding historical BIM development, current status, dimensions of BIM and BIM importance in different design and construction stages.

The latest existing technology has many effects and benefits in construction projects. The success of Building Information Modelling (BIM) lies in enhancing the collaborative process of design and engineering. The contributors to the design and constructions are provided with an integrated database of coordinated information.

In the current AEC industry, many essays explore BIM's potential for an architectural design. All the authors provide insights and evaluation of current practice and research directions of BIM.

As revolutionary virtual technology that helps to create higher quality and more accurate designs and documentation of construction projects, BIM provides work within a coordinated, 3D model-based environment that automatically updates designs when changes are made.

Adding a 4th dimension (4D) allows the schedule to be linked with data objects at an appropriate level of detail. The project is then built visually testing different options. This gives the opportunity to try many options before deciding on the best one (Eastman *et al.*, 2011a). The 4D model simulation addresses the issue of construction operations by providing views of activities during any period of construction.

2.2 Historical development

In the early 1990s, 2D drawing systems in the construction industry were used only as "electronic drawing boards". The work on the board was delivered by copying and pasting details or blocks, providing quicker drawings than the older manual processes. However, the technologies and the processes behind BIM have been evolving for the last 40 years.

Early researchers started their work in the 1970s and nowadays they still invest in the research and drive the industry forward toward BIM (Eastman *et al*., 2011b).

Eastman described his working prototype in 1975 in his paper "The use of computer instead of drawings in building design". His working prototype "Building Description System" (BDS) includes the idea of the parametric design, creating 2D drawings from a model and use of a single database for visual and measurable analysis. At that time, he also suggested that contractors would be able to use the database for scheduling and material ordering. BIM capabilities could be recognized in his description seven years before Autodesk was established and 25 years before Autodesk released a first version of Revit (CODEBIM, 2015a).

Later in the 1980s, as the research continued, the BDS system was acknowledged as "Building Product Models" in the US and in Europe as "Product Information Models". Robert Aish, the member of Autodesk, first used the term "Building Modelling" in 1986, and Phil Bernastein, a FAIA architect, first used the abbreviation BIM for Building Information Modelling and then Jerry Laiserin helped popularise the term as a common name (Granholm, 2011).

The importance of BIM is not in its name but in providing more collaboration in the construction industry, making useful technologies available to improve information flow, reduce errors and increase efficiency (CODEBIM, 2015b).

With 'Information Modeling' all the information required for the manufacture and construction of a building or structure are represented as intelligent objects and elements. The relevant information of these smart objects includes knowledge of what the elements are, how to behave in different circumstances as well as their own properties and validity.

In a series of "Smart Objects", Building Information Model carries all information related to the building including its physical and functional characteristics. BIM provides consistent and coordinated views of the digital model. The reliable data is provided for each view. Each view is coordinated through the built-in intelligence of the model which saves the designer's time during the design process (Azhar *et al.*, 2008).

3D modelling was firstly attractive to the structural steelwork industry 20 years ago. The software used for the steel structure allowed the user to model a 3D steel frame and to apply the connection by the user-defined macros. There were possibilities for automatic production of general organized drawings and fabrication details. Later on, application provided developments in clash detection. These new applications had a capability to detect conditions such as any material or objects overlapping.

In the beginning, BIM applications were suitable only for very powerful computers but with the advance of computer technology, the BIM models could be applied on laptops and even tablets.

2.3 Current status

The associated elements of 3D BIM with time and scheduling information present and connect the spatial and temporal components of the construction schedule, better known as 4D BIM. This 4D BIM tool has an impact on Integrated Project Delivery (IPD) but the scheduling techniques and the cooperation among all project participants need consideration. The communication issues during the construction projects as well as the task scheduling have not been deliberated enough, although they are the reasons for some problems that arise during the commence of the project. This study highlights the components required for the successful 4D simulation and suggests the approach to improve its conception and project delivery.

Today, Building Information Modelling has many definitions. The most common definition indicates that BIM is a modelling technology and a set of processes that produce, communicate and analyse building models. BIM is now a worldwide digital technology which is broadly presumed to have the ability to reform the construction industry. In recent years, governments in many countries have been encouraging the use of BIM as a means of assisting collaboration and increase delivery efficiency and project quality. However, government encouragement has not led to satisfactory acceptance of BIM. BIM success relies on the effectiveness of information exchange and significant capabilities. This is the fundamental conception of the interoperability of BIM system (Abanda *et al*., 2015).

The evolution of BIM gives the opportunity for early planning, improvement of conditions and prefabrication of components (Bernstein, 2010). Although the technology has been present for almost 40 years, it is only in the last decade that BIM has begun to receive attention from the industry at government level (Azhar, 2012a).

Primary reasons for the use of BIM are that it:

- Saves time and money
- Makes construction site / process greener
- Makes construction site / process safer

BIM has a long list of advantages as a tool for achieving leaner and greener designs in terms of energy and material use during the construction, usage, maintenance and demolition phases. All parties involved in the project benefit from BIM. The advantage of BIM applications for architects and engineers can be seen at different stages of the project design. Schematic Design (SD), Detailed Design (DD), and Construction Detailing (CD) benefit from specific BIM applications in different project stages (Azhar, 2012b).

Adopting BIM is more about a process change; it is not about where to adopt BIM, but how to implement BIM in the AEC industry. However, adopting BIM in practice is not an easy process. Therefore, it is necessary to know how to set up BIM processes and protocols to maximize the benefits. Some construction organizations think of BIM as software which is a mistake that leads to BIM being used for targeted tasks. This misunderstanding of the technology creates obstacles for the technology to reach its full potential. The current status shows lack of planning in general and inadequate guiding principles offered to project participants involved in the BIM process (Modern Building Services, 2011).

More effort is needed in implementing BIM as the challenges are growing with construction project complexity. The transition to BIM includes engaging people in the adoption process by increasing people skills and understanding. Staff training and managing resistance to change are crucial for successful BIM implementation (Smith and Tardif, 2009a).

A company's implementation strategy should consider how existing 2D drafting will coexist with 3D applications. The fact that BIM is not all 3D could also be used as encouragement to the companies willing to change. Within 3D BIM models are a number of components which could be signified as 2D objects, or only listed as data as in the schedule. However, the key for successful BIM implementation is recognizing that many processes, whether a design, construction or property ownership enterprise, are part of a system.

It is also important to be known that any building information created by one person in the system is of the same value for everyone else in the system. To put BIM smoothly into use, a company needs to develop a sound, comprehensive implementation strategy, assemble the right team, and select a suitable starting project (Smith and Tardif, 2009b).

The research indicates the companies that have succeeded in this transition witnessed the substantial shift from the CAD 2D drafting method to BIM modelling virtual prototypes. They all agree the product of digital prototype of a building helped them to understand a structure's behaviour before its construction. Companies experienced in using BIM praise the technology as highly effective in linking design and construction teams by improving their communication.

The development of Industry Foundation Classes (IFC) and aecXML allow all the team members involved in the project to view BIM models. This data structure for demonstrating information used in BIM was developed by buildingSMART (International Alliance for Interoperability). Furthermore, it is important to indicate that BIM modelling is not 3D modelling. BIM models are represented as three dimensional models, however a 3D model does not incorporate all the information a BIM model contains (Aouad *et al.,* 2012a).

Integrated design process is the best solution for green design with a complex approach to design and construction disciplines. BIM incorporates the ability to make work on integrated design much easier. With its visual realisation capabilities, BIM shows actual benefits to all stakeholders of a construction project. BIM offers real-time cross section solutions which provide "Integrated Project Delivery" which is an exceptional concept in the AEC industry.

2.3.1 Dimensions of BIM

As BIM technology allows many aspects of a project to be brought to everyone's attention and considered earlier than a project that starts on site, there have been some additions to the 2D/3D concept. Adding the aspect of time, cost or life cycle management to 3D models are recognized as BIM dimensions 4D, 5D 6D and lately even 7D. These different BIM dimensions are designed to simplify and clarify the functionality of numerous BIM processes (Redbike, 2013a).

2.3.1.1 2D BIM

Starting with two dimensions, having plan, elevation, section and detail drawings where designers define visualize the building form, is the initial point even for a BIM model. However, the traditional 2D building design has been extended to a 3D building design with primary spatial dimensions width, length and height to present the building design as well as to visually analyse and improve the project (Redbike, 2013b).

2.3.1.2 3D BIM

The 3D BIM model demonstrates all construction stages that create a virtual model of building elements and provides even greater opportunities. For example, it is possible to detect collisions visually and to report the design issues in order to prevent construction errors (Redbike, 2013c).

2.3.1.3 4D BIM

To create a 4D model, a time element is attached to a 3D model which allows it to show the building process through animation. A 4D model is not only visual media which enables users to simulate the construction process, but it also provides further ability to enhance and control the construction progression. The BIM concept is visually created as each component task allows its start and end time. The construction management level, logistics and planning can be assisted with a 4D BIM (Zhang and Hu, 2011a).

2.3.1.4 5D BIM

The fifth dimension (5D) is about adding the cost feature to a project. Cost estimate in a 5D BIM offers the tool to indicate inside BIM where substantial costs arise and also where in the time-line in the construction process such peaks take place. A 5D BIM provides more effective assessing and budgeting. For instance, when certain element quantities and costs are known in the project, it is then possible to estimate material, labour and equipment costs. This capability allows construction to be more predictable as the combination of geometry, income and procedures are integrated in the BIM model (Storer, 2012).

2.3.1.5 6D BIM

The sixth dimension (6D) is the phase of life cycle management when the project is completed. 6D BIM is an as-built model, the final product delivered being to the owner or facility manager. This BIM dimension is additional BIM power incorporating information about room components (room name, space type and number) linked to information about the manufacturer, serial or model number and any other information of importance for maintenance (Redbike, 2013d). Most recently the discussion introduced 7D BIM for facility management to be used for operation and maintenance of the building throughout the facility life cycle. In this scenario, 6D BIM should be mainly used for energy consumption analyses. Accurate energy estimation in the early design process would increase construction sustainability (Impararia, 2014).

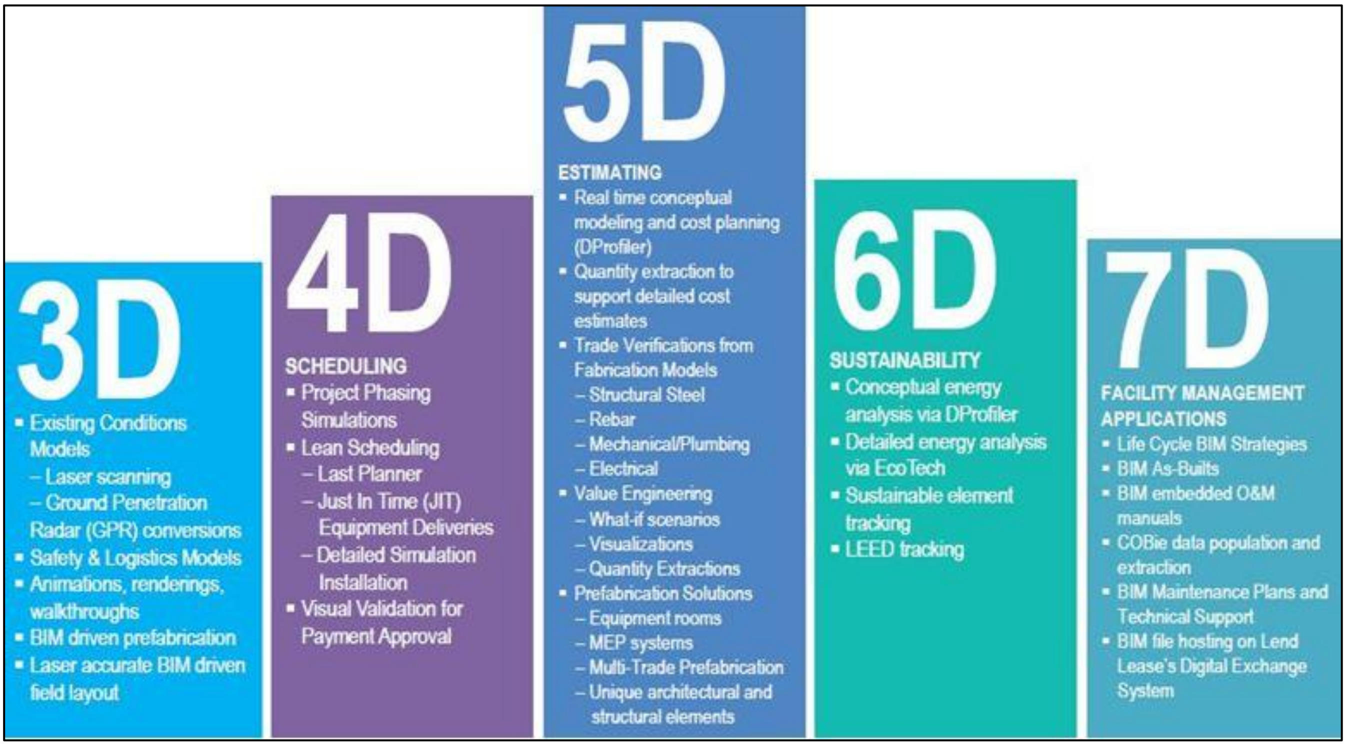

Figure 2.1: The dimensions explained

(Source: BIMTalk, 2013)

More recently, construction projects have been complex structures. Therefore, it is expected that the greater amount of data information storage capacity will become even more important for monitoring and managing of a building's sustainability performance. The integrated design information and collaboration through BIM supports environmentally sustainable building progress (Wong and Zhou, 2015).

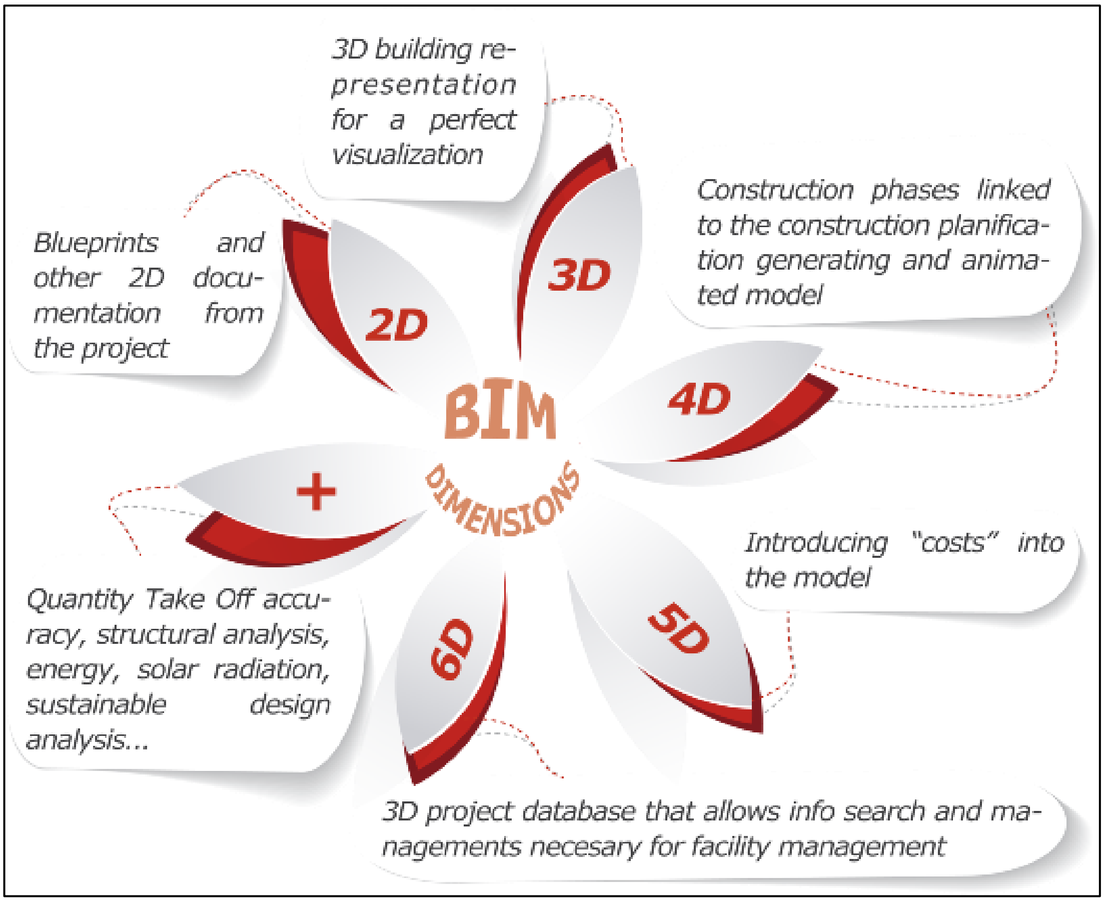

Figure 2.2: Dimensions of BIM

(Source: BaboonLab, 2015)

2.3.2 BIM in the preconstruction phase

This study recognizes the close relationship between design and construction. Therefore the attention needs to be paid to the role of BIM in the preconstruction phase. The study sees the importance of including the temporal structures and temporally works in construction planning to make design a physical reality.

In their study, Cheng and Chang (2018) argued about how the temporal structure can be included into the 4D simulation. In their opinion, the use of 4D BIM in the constructability analyses during the pre-construction stage could enhance 4D simulation. This initiates the need even further for the project planning, grater communication and closer look into the level of detail.

Using BIM models, the project team also benefits in the preconstruction phase in estimating site construction, and constructability analyses. In this phase, an advanced approach to the project will provide insurance that the project proceeds smoothly and meets its deadline and budget.

Careful consideration of existing conditions at the site such as lay down area, material deliveries and removal, as well as equipment and road access are critical to preconstruction planning that is provided with BIM tools.

In the conceptual design of the 3D BIM model, when the massing, placement and the form of the structure has to be decided, the creation of modified and easily moved 3D objects in making design decisions are significant. Once the all sides are satisfied with the income of conventional design more details can be added in order to use complex design (Aouad *et al.*, 2012b).

During this stage of design, the design review by design professionals involved in the project is important for cost efficiency and quality design solutions. In the preconstruction phase, the design team has to communicate with engineers and the client, who is the major stakeholder, in order to find best solutions for design and therefore meet the client’s needs. This communication is done by the visualization of the 3D BIM model. The visualization can include a 3D design, documentation and detailing, and rendering and graphical representation.

For the building design during the preconstruction phase, certain issues have to be considered such as quantification and estimation, spatial coordination and clash detection, carbon footprint and sustainability, fire analysis, as well as code compliance checks (Aouad *et al.*, 2012c).

2.3.2.1 Project planning

The use of 4D BIM in planning purposes refers to continues review and notification of all the onsite activities. The planning includes the project schedules which is competent to track and visualize construction progress according to updates in the schedule. This study takes into consideration the frequency of the schedule update as one of the factors for improving the 4D simulation images.

Project delivery method is still a huge challenge and obstacle for wider and full acceptance of BIM. The traditional methods of the building such as Design Bid Build or Construction

Manager at Risk limit BIM's potential by not understanding the planning and communication importance in the construction project. However, the traditional methods of project delivery bring comfort to the owner for the reason of being the method used for many years. Another reason is the opinion that the traditional methods are the cheapest methods. Nevertheless, it is advisable to consider the possibility of redesign or any other additional expense and risk occurring during the project.

Furthermore, the limited or non-communication between the designers and the contractors produces the friction between the architects, engineers and contractors. For this reason, there has been an acceptance of Design Build method where a substantial quantity of team building and team collaboration is seen as the key to successful project delivery. Having trust and cooperation within the team using this method, where information is shared, accelerates the project using complete leverage of BIM tools and practices. In this delivery method, the project owner and the contractors carry a great amount of risk and accountability. However, the trust among team players leads the project to be a success (Hardin and McCool, 2015a).

The Integrated Project Deliver method promotes the concept of sharing the risk between the owner, architect and contractor. It is very important to indicate that by sharing the risk, the reward is then shared too. The accomplished results will determine whether compensation increases or decreases but every member of the entire project team is affected equally. The shared responsibilities in Integrated Project Delivery raise communication to a higher level and encourage strong collaboration among the project team.

Understanding the necessity of accountability increases the creativity and innovation of the design by all team members. This method is a huge challenge for the AEC industry and has not yet been fully accepted by public organizations.

Gathering professionals who work on a complicated net of process raises the need for the project planning system. The construction planning is recognized as vital to limiting the possibility of later construction delays and budget overruns.

All the construction experiences point out that the preconstruction phase cannot start with using BIM without an execution plan or information exchange plan. Skipping the formation of the execution plan and starting directly with BIM thoroughly limits a team's ability to carry out the project successfully (Hardin and McCool, 2015b).

2.3.2.2 Detailing and documentation

This research argues the types of detailing in BIM simulation, the graphical and the temporal detailing, and they are both still relying on the 3D BIM level of detail. The study is instigated by the need of improving the 4D dynamic elements in order to achieve more reliable results. As a construction project is a vibrant event and 4D simulation relays on the documented commenced tasks the outcome should be the active and vivid 4D visualization, yet, that is not the case. There has not been a certain investigation made to date how this could be amended.

A high level of detailing is very important for a BIM design. The literature undertaken in this research points out that wrong and inaccurate detailing causes delayed project delivery and makes the project more expensive. The BIM capability used in detailing and documentation allows the designer to visualize the physical character and dimensional detail. This detailing can be used as a requirement for a build-up of any building element. This is then kept as the documented text in the BIM database (Aouad *et al.*, 2012d).

2.3.2.3 Graphical representation and rendering

The multiplicity of software used to build a BIM model has good rendering capability. This is helpful in developing the BIM model and achieving the desired concept. The latest BIM capabilities are especially supportive in presenting the completed concept stage of the building to the client, as the idea given in a BIM model is usually easily understood (Aouad *et al.*, 2012e).

2.3.2.4 Analyses

Throughout the design stage in BIM modelling analyses of the quantification and cost estimation, fire analyses, code compliance checks, clash detection and energy efficiency attributes contribute to the completion of a BIM model.

Computing building information in BIM allows the estimator / quantity survey to do cost-estimating. This information incorporates the type, dimensions and number of all building elements. With this information, it is easy to measure the amount of materials needed using the model.

Fire safety issues indicated in the documentation of building regulations are one the most important analyses in the construction business. The fire resistant building materials are listed in a BIM model database. The capability of BIM model visualization allows an architect to address the issue in the design stage.

Ensuring all government regulations comply with the BIM model is something that is carried out automatically. BIM digital database stores and identifies objects, spaces and facility of the BIM model (Madsen, 2008). A BIM model can be checked through the use of the auto code check tool “buildingSMART”. The “buildingSMART” tool provides automatic access to international energy conservation codes and also international fire codes, seismic codes or mechanical codes (Aouad *et al*, 2012f).

Model clashes caused in designing models that are created by different professionals are very common in a BIM model. The architect, structural consultant and MEP consultant come up with different BIM models which result in design disagreements. Clashes can be:

- Hard clashes – the same physical space occupied by two objects
- Soft clashes – the occupation of the space by the wrong object
- Time dependent clashes – the arrangement made in a model which cannot happen in reality

The goal of the construction industry is to create environmentally friendly designs that lead to construction which will reduce the negative impact on the environment. Sustainability is helped by BIM as its processes can help in enlightening energy efficiency aspects in multiple design alternatives. The possibility of calculating the southern orientation for the day lighting and the capability for views of each feature helps the creation of sustainable design. Calculated details initiate the creation of the design in order to fully use sunlight with the best position and size of the south facing windows. BIM boosts this activity as the BIM model can be positioned depending of the sun’s angle at different times of the day and year (Aouad *et al*, 2012g).

2.3.3 BIM for Facility Management (FM)

Operation and maintenance are repeatedly ignored at the design phase by the owner and project participants although they could evaluate over half of the total building life cycle cost (Becerik-Gerber *et al.*, 2012). Documents and information delivery to the FM period is left until the accomplishment of the construction phase and information is usually handed over in manual or non-digital format. As the unstructured data is delivered very late, it is very challenging for facility managers and owners to evaluate whether the received document includes the information they need.

Moreover, the handover of such data and information to FM systems is a costly and time consuming procedure. These additional processes result in extended periods before optimal building function can be reached as decisions regarding maintenance, energy and safety at the facility management phase are delayed. The FM data and information come from various sources, therefore the records are collected from different fields and disciplines. This non-synchronised data causes processes to be error-prone during the structure life cycle.

BIM technologies, workflows and open standards opened the new chapter for integrating the FM phase with the upstream project delivery phase. Proper implementation and management of BIM technologies and processes provide the management and incorporation of the information required for FM through the asset-life cycle phases that can be tracked back nearly 15 years (Patacas *et al*., 2015a).

Implementing BIM in operation, the phase has a positive impact on cost efficiency, savings and increases asset quality. It would be possible to achieve this if design teams engaged facilities management through BIM at the earliest stage of the project. Facility lifespan information of building components should be considered from the early design phases of building development. The data integrated in a BIM model incorporates all the specifics of the physical building. The dynamic information contains the manufacturer, part number or any other information about the structure support analysis, operation and maintenance of the building (Wang and Chong, 2015).

Once again, this research comes to the baseline of the 4D model, which is a detailed 4D simulation based on 4D visualization and dynamic feedback. This dynamic feedback assumes to be a persistent method of updates informed from schedule amendments and actual activity progress. Here arises the question how often the changes were made and would the 4D simulation be the most trustworthy tool for Facility Management to rely on? Thus, the research highlights and takes into consideration the importance of the frequency of the captured changes.

This BIM capability of delivering digital data and information to the Facility Management is provided by open standards Industry Foundation Classes (IFC) and data structure specifications such as COBie. IFC is a specific BIM format used to represent building models in object oriented data and it will be considered further later in this study. Construction Operation Building information Exchange (COBie) is information that makes the work of capturing, recording and distributing project information for the client easier. COBie is a subdivision of the IFC model, created on the Facilities Delivery model view definition, and it can be used to define the owner/client's requests and establish support for the realization of FM tasks.

Open BIM standards and data structure specifications provide the possibility to record and define information processes through the life cycle of a constructed facility. The role of facilities management is to operate, maintain, improve and adapt building and infrastructure assets in order to support the main objective of the occupants, owners and facility managers (Atkin and Brooks, 2009). BuildingSMART continues to develop BIM open standards with IFC and COBie having constant input from AEC and Operation industries (Patacas *et al.*, 2015b).

2.3.4 IFC development

In 1994, Autodesk formed an industry association to advise the company on the creation of a program that could support incorporated application development. The group consisted of the twelve United States companies at first named the Industry Alliance for Interoperability. In 1995, this organization opened membership to all interested parties and in 1997 they changed their name into International Alliance for Interoperability. The organization became non-profit and its aim was delivering the Industry Foundation Classes as a neutral part, the AEC product model. In 2005, the IFC specification was developed and maintained by buildingSMART.

From its development in 1994 until 2005, IFC went through different stages of the standardization process. The main idea of the developing IFC standard was to "develop practical user capabilities for data exchange" (Eastman, 1999, p.314). IFC indication was always to be a high-level data model with a consistent data structure for the storage of building information yet it does not allow any exact way of applying it into software. Direct structure containing IFC data can be compressed into libraries for physical file-based exchange or the IFC files can be signified in an object-oriented folder and be updated regularly over the internet in practical terms.

The arrangement of the IFC data model was divided into four layers: domain, interoperability, core and resource layers. All the layers have exact referencing orders which are downwards in IFC hierarchy where a resource layer is independent and references no classes above it. The other layers can all reference records from the resource layer besides all other layers below them. The store system that holds elementary definitions planned for defining objects in the above layers is in the resource layer. The core layer is made up of the kernel and extension models. The kernel regulates the model structure and analysis offering basic concepts of objects, relationships attributes and roles. The extension models are information about classes outlined in the kernel. The interoperability layer is responsible for the interconnection for domain models therefore this layer makes available an exchange mechanism for allowing interoperability across domains. The domain layer incorporates domain models for progressions in specific AEC fields or varieties of applicators such as architecture, structural engineering and others (Laakso and Kiviniemi, 2012a).

Structure of the IFC 1.0 – IFC 1.5.1 data model was launched in September 1995 and published in January 1997. This format contained narrow opportunities and concentrated on the architectural part of the building model. The format combined five processes for architecture, two for HVAC design, two for construction management and one for facilities management.

IFC format 2.0 was released in 1999 and incorporated schemes for building services, cost estimation and construction planning. However, in practice, IFC 1.0, 15.1 and 2.0 were indifferent to what was at first announced and their usability in construction projects was considered poor.

Furthermore, it is necessary to point out that in the meantime, the consortium became global including companies from Australia, China, Italy and Korea. In 2005, the fundamental status of IFC 2x achieving ISO/PAS1673 was established. In 2001, it started the development of ifcXML format, the official representative of IFC. In addition, it should be indicated that there were some format public sector interests in BIM and IFC which grew in 2007 in extent for BIM with IFC deliverables (Laakso and Kiviniemi, 2012b).

High levels of commitment to IFC through BIM followed up in Finland, Norway, Australia and Singapore. The research and development projects worldwide assisted as significant standardization resources in implementing IFC in construction projects.

2.3.4.1 IFC in conclusion

IFC was developed as standardized data sets for exchange and sharing BIM data between applications for 4D simulation approach visualizing 3D building models. The IFC format offers the possibility to compare as-built elements from model images with as-planned models providing the percentage of completed construction tasks.

A starting point schedule and progress is mostly used to evaluate concrete progress to conclude which activities started earlier or later than planned. Throughout the construction stages, an analytical plan is considered to be the starting point value made during a construction project. All baselines become expected values and finally these values become real progress. When the project evolution is represented with a 4D model, the deviation and differences between anticipated and actual time are vital to directly evaluate the proportion of accomplishment of a product and work. The time deviation factor and plan inconsistency in most of the projects is similar to the percentage of the construction components completed. The differences between the expected time and the real-time are measured in contrast to the estimated percentage of the assigned construction components that have been used. In the last part of the project, length and work changes can be presented with BIM during the course of product model-based factors and recordings. In the end, work adjustment and other project information management coordination can be automatically updated with as-built information (Roh *et al.*, 2011).

2.3.5 BIM in prefabrication

The construction industry has been making a huge effort to reduce waste and save money in any construction project. Prefabrication of the building components with a BIM technology has been promising in large and complex projects. Using BIM tools, the general contractors or construction managers prefabricate mechanical, electrical and plumbing equipment in order to identify the production of the needed building elements. In this case, the waste is reduced as the production of unnecessary and unwanted products is prevented (Yoders, 2015a).

Collaborative team work, where architects, engineers and constructors work together, the possibility of prefabrication is achievable from the conceptual design phase throughout the whole building development. However, it is important to point out that integrated and prefabricated does not mean limited as BIM allows prefabrication to be flexible, as long as the model is buildable by computer applications and the elements can be prefabricated and installed (Yoders, 2015b).

Furthermore, prefabrication reduces field labour cost, provides more precise jobsite performance as well as increases accuracy in construction. The high level of accuracy depends on incorporated specifications, sequence, finished and 3D visibility of each element. Prefabrication of steel connections, beam penetrations, roof penetrations, curtain wall systems, which orders come from virtually designed and constructed a BIM model, save a tremendous amount of time for all project professionals.

Overall, the prefabrication business plays a crucial role in the collaboration of information exchanged between the subcontractors. BIM can be used to improve information sharing of the products among the project participants. Created on this information, the products can be detailed in depth using the fabrication software used by fabricators. The construction team has to collaborate with fabricators making sure BIM is interoperable with the software they use in the prefabrication process (Hergunsel, 2011).

2.3.6 BIM in renovation processes

4D BIM can be used in renovation processes to track down the renovation evolvement by recording current building information in order to minimize errors. This research includes this BIM capability as its main benefit in the renovation is in coordination, visualization, and energy simulation. These 4D BIM features depend on communication among project participants and the information they pass to one another whether the information is geometric or non-geometric. This study indicates the importance of the level of detail in any building project lifecycle, as the level of detail assists effective visualization and data analysis.

In addition to the recognition of the importance of using BIM in new construction, there is also a recognition of the significance of BIM in renovation processes. Current situation initiates the need for keeping and reuse the buildings as more affordable than taking a structure down and build a new one (Jones, 2011).

In the renovation process, BIM helps to achieve environmental, financial and social benefits. These goals are achieved through the process known as “Scan to BIM” in which 3D scans taken from surveys are used to create a real-time BIM model in the renovation project. This process saves resources that would be used for the new construction (Randall and Philip, 2013a).

3D Laser Scanning is a three-dimensional measurement device which collects 3D co-ordinates of a given region or of an object's surface. Laser scanning co-ordinates are XYZ and together they form a figure known as point cloud. The point cloud can incorporate colour qualities or return intensity, where a colour model combines red, green and blue light giving broad areas of colours. This improves the model visualization, giving more realistic images and therefore helps BIM efficiency in a given task (Randall and Philip, 2013b).

2.3.7 BIM in the construction phase

Moving to the importance of BIM in the construction phase, this study over again comes to the point in the literature where the argument about sufficient information is indicated for helping the construction phase in preventing costly errors. The constant information update means the constant collaboration where all participants have the same goal in the project commence, to work with the flow and smooth task transition during the project. This study seeks a relevant 4D method in these aspects in order to provide a breakthrough which would benefit the AEC industry.

In the construction phase, BIM is used in project progression monitoring and for trade coordination meetings. All the building specifications produced by the designer are stored in a BIM database and it can be referenced, displayed and quantified. Providing planning and scheduling of BIM models is vital for saving time and cost. The time element gives the scheduling additional strength. The use of a 3D model plus time and the creation of a 4D model allow a BIM model to be integrated with other software programs. Various building construction tasks are then organized gradually along a timeline.

As the construction moves on, the different professionals will join the project delivery process. The trade coordination has to be well navigated in order to avoid time overlaps. The contractor has to understand the order of the tasks to make the trade coordination run smoothly as some of the trades cannot function at the same time. A virtual construction exercise helps achieve trade coordination, as BIM simulates the building construction in a virtual environment that is of great assistance in the construction phase enabling visualization of the details at any specified time.

Visualization during construction prevents costly errors as the information is absorbed and acknowledged more easily. The testing and evolution of any situation makes it possible to find the best solution during construction. During the construction period, the BIM model has to be continuously updated which would reflect the most up to date information. This information could be used later by facility managers for building operations and maintenance (Azhar, 2012c).

2.3.7.1 BIM for Health and Safety

This study wants to indicate that the dynamic prediction models could be achieved with alternating earliest plans of different construction stages and tasks where safety-connected accomplishments would be included into the construction schedule. However, all the enabling safety correlated modelling need amount of information for safety equipment directly form BIM.

Health and Safety (H&S) in construction processes has been the subject of studies and research projects as the construction industry is one of the most dangerous industries to work in. Studies and research projects are very much directed at how to reduce risks inherent within the industry (McDonald *et al.*, 2009). Commonly, construction accidents are initiated by human factors whether from employees' competency or behavioural traits (Addison *et al.*, 2013). Workers have to be trained in order to increase the awareness of the site danger and therefore improve health and safety in the course of construction projects (Dawood *et al.*, 2014).

As the whole project has to be planned, planning for safety would include identifying all potential hazards, and in addition include decisions on indicating consistent safety measures. Safety planning is a separate process from the project execution plan and involves different participants. This lack of communication among project actors creates difficulties for safety engineers to precisely identify potential hazards on the site.

Implementing BIM into construction practices has led to the improvement in the way safety can be approached. Using the building model and associated schedule it is possible to detect and eliminate hazards as the construction site changes daily. BIM provides the possibility for safety in construction, design and planning. BIM models enable the incorporation of construction safety and health practices. BIM tools allow the user to identify dangerous sequences at the planning stages, and by being corrected, reduce risk of onsite accidents.

BIM applications offer a rule-based checking system that evaluates building design on the basis of building objects configuration. Rule-based schemes support the user to state and apply rules that recognize settings of importance in the model by completing them on a given model and returning the information which mainly consists of “pass” or “fail”. This BIM design evaluation is performed with simulations that can be delivered through automated interfaces more quickly and consistently (Zhang *et al*., 2013a).

As safety rules already exist, they can be used by combining them with existing three-dimensional designs and schedule information to communicate an automated safety rule checking system. This means using virtual 3D space for providing solutions and visualizing protective systems to diminish any identified hazard. This platform could be used for tracking progress on construction and safety over time. Being aware of dangerous hazard locations on the site, safety managers could plan safer performance of work tasks upfront. Their monitoring of the scheduled work tasks for the duration of construction phase could be easily accessible as well (Zhang *et al*., 2013b).

Furthermore, the new development in 4D BIM technology presents structural information models according to the overall solution of analysis and management for clashes and safety problems during construction. 4D technology is used for structural safety analysis by regulating the construction plan or design of the framework system in case of security risk. These structural analyses include the calculation and automated dismissing of resistance of each element and the load effect by using design codes and stochastic simulation. The control and calculation of stresses, strains and displacements can be done at any time point. Using the structural safety performance indicators, the overall safety performance of the structure could be evaluated. Managing the site, measured data dynamic prediction models can be applied to revise the evaluation of site safety (Zhang and Hu, 2011b).

Modelling and visualizing the construction process and consenting users to simulate construction processes is becoming significant for construction health and safety. When investigating in a 3D environment before the commencement of actual construction, it is possible to identify potential dangers. The visualizing technology provides the possibility of repeating the process and detection of possible hazards that otherwise would not be possible to point out (Chun and Li, 2012).

2.3.8 BIM advantages

The advances in BIM technology have allowed BIM movement to progress and to gradually replace CAD systems. As BIM represents the process of the development and BIM adaptations grow on the market, this technology will continue to flourish.

Researchers identified advantages given in a BIM strategy indicating that these advantages help BIM popularity to increase: Building Information Modelling increases design productivity because of the easy access, transfer and storage of information (Eastman *et al*., 2011c; Huang *et al*., 2009a). This information management also helps in cost and time savings.

The possibility to explore more choices in early design using visualization saves time and provide opportunity for cost estimate (Shen and Issa, 2010). BIM improves construction planning and advances the harmonization of the construction document. When the change is made in one place, the update will be done in every part of the design. BIM tools allow user to identify problem areas within the design very quickly (Eastman *et al*., 2011d).

Industry professionals' interaction and sharing of digital datasets is provided by Industry Foundation Classes (IFC) which is delivered by using BIM technology. Incorporating names of vendors of specific material, the location of used components or measurement required for appraisal and presenting is another of BIM advantages. Building Information Modelling tolerates more flexibility in the project design before the real construction. The collaborative work of the owner, designer and contractor working on the model allow them to implement changes easily.

During the course of a project any of the needed documentation can be extracted from the BIM model as all parties included in work share the same model. Valuable analysis is provided by BIM analysis tools which allow different professions in construction to extract data from the design process. Any set of data required can be acquired from the work done in the BIM process. Probably the major benefit is the ability to produce a number of 3D views that are more easily understood without difficulty than the old style plans and elevations. BIM allows the user to have an insight into the amounts, numbers and measure of certain types of materials necessary for the design.

High accuracy level required by architectural and engineering representation is important as these elements have to be suitable and fit easily inside the integrated data environment. The BIM process is faster and more effective as the information is shared, can be estimated, further developed and reused. BIM offers better design as building tenders can be carefully analysed, design visualization can be achieved quickly, support improved and inventive solutions provided. BIM models can be used to understand and support the environment performance of a facility (Albert, 2014a).

Use of BIM data in order to ensure that findings and decisions are made on the foundation of whole-life costs helps facilities management. Bids are better understood through correct visualization of lifespan data constraints. Therefore, facilities management can use design, construction and operational information for the better operation and maintenance of the building (Albert, 2014b).

Everything considered, numerous readings outline BIM through the benefits, including parametric modelling (Huang *et al.*, 2009b), in depth building analysis (Krygiel *et al*., 2008), 4D programming in which the construction programme is linked into the building model (Mahalingam *et al*., 2010). Using 4D BIM for planning and scheduling permits simulating and interrelating with construction sequences. Planners are able to detect and resolve schedule conflicts, track and manage workers and resources making sure they are applied effectively.

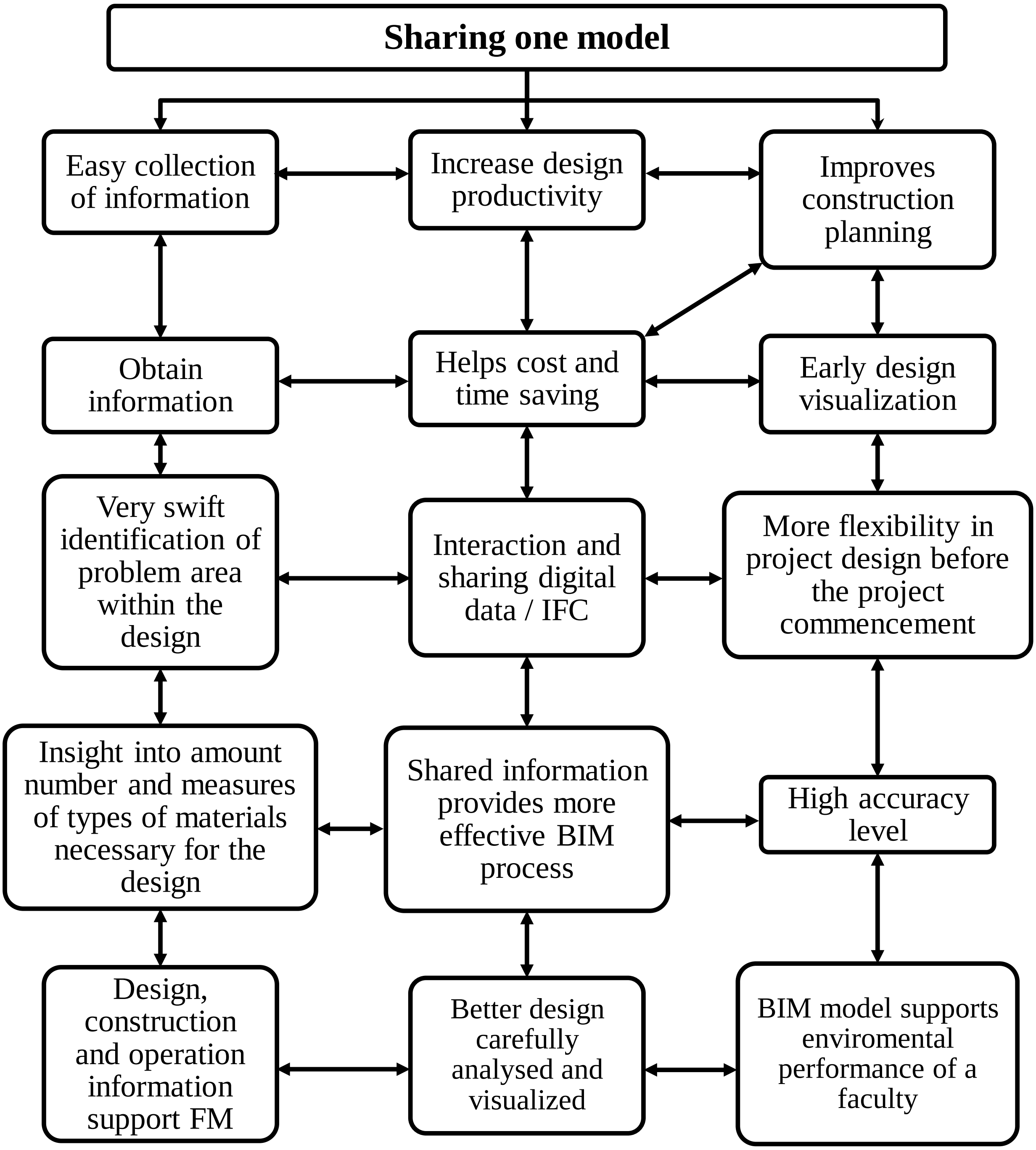

Figure 2.3: BIM Advantages

(Source: Albert, 2014)

2.3.9 BIM limitations / challenges

It is commonly said that BIM's benefits far outweigh its weaknesses and that changes frequently as increasing AEC/FM professionals implement (Albert, 2014c).

The limitation or challenges of implementing BIM are mostly focused on software or hardware issues. These limitations seem to relate to the management of change associated with the adaptation of BIM and could be addresses with such initiatives as better training for all employees involved and stakeholder engagement activities to allow key actors to get used to a new way of working (Bryde *et al.*, 2013).

The growth of demand for well-trained designers and construction managers created innovation within the AEC industry as the industry lacked well-trained designers and construction professionals. It could be very costly if an accuracy error occurred in the BIM project. The BIM plans are formed from the model. Therefore, they all replicate the same data, making it harder to catch small inaccuracies that can lead to bigger problems. The companies that try to incorporate BIM in their existing processes often find it is time consuming and software and hardware costs are high (Albert, 2014d).

The limitation could be also seen in the capabilities of the software currently used, particularly 4D software. The time related information associated with different components in 4D BIM benefits planning work to maximise efficiency of the project. However, the conflicts that occur during the construction which are key usages of 4D modelling are spatiotemporal conflict analyses. The clashes take place when an activity's space constraint affect with one another or with a work in place (Akinci *et. al.*, 2002). The challenges are in unforeseen and undetected clashes' and tasks' duration.

2.4 Summary

BIM is acknowledged as an evolving technology supported process that can profoundly improves the project delivery. However, there are still some research which postulates that the full potential of BIM has yet to be reached. The combination of other technologies with BIM must work together with suitable executive methods and strategy. It is assumed that this is an important step in handling the challenges of BIM. Different management categories and contract administration are responsible for different stages of BIM implementation and maturity. Although BIM is still developing its database system, lean concept and Integrated Project Delivery will still need to be researched in order to bridge the gap between theoretical evidence and industrial practice.

However, the collaboration of all involved parties at the very beginning of the construction project is crucial, as well as all the way through different project stages. Management must insist on this collaboration and to incorporate newly defined roles, in order to unleash the full potential of BIM.

4D planning and scheduling can be used as communication tool by visualising closely what the plan requires by simulating the construction schedule. Even the jobs that come later in the project such as deadlines, sequences, or resource consumption planers should foresee and plan ahead of time.

The terms and merits of 4D modelling will be discussed in next chapter as this study is concentrated around the potentials of 4D BIM and the concept of level of detail in this BIM dimension.

Chapter 3: 4D Modelling

3.1 Introduction

This chapter will critically assess the work done in the area of 4D modelling with the emphasis on information visualization and the role of the level of detail in 4D simulation. Beginning with the historical background of 4D modelling, the chapter will also explore previous research related to the capabilities of 4D technology.

Four-dimensional CAD modelling has been recognized as the tool which improves construction planning techniques. The combination of 3D CAD with the schedule data has been quoted as the indicator of design and planning errors in many construction projects. The integration of 4D modelling tools with 3D models graphically simulates the construction process.

4D model elements connected in 3D CAD models allow project stakeholders to view all the accomplishments from design, procurement and construction schedules. All the planned construction of a building over time is shown on the screen and provides a 3D CAD model review for any day, week, or month of the project.

Furthermore, 4D CAD helps different project contributors to understand and comment on the project options in a practical and well-timed manner. 4D models allow the consideration in advance of the effectiveness of the project approach, progression in the constructability with consistent improvements in on-site efficiency, and the shift documentation and resolution of time-space clashes.

Current status shows that even though there is room for improvement existing, 3D and 4D tools provide substantial assistance to the project team. The 4D technology supports the evolution of synchronised and constructible designs and construction classifications. Project teams are helped by 3D and 4D models that recognize design clashes, sequencing limitations, access issues, manufacture details as well as procurement restrictions that impact the effectiveness of the project delivery process (Eastman *et al.*, 2011e).

In addition, it is believed that the use of these tools helps project participants reduce risk and attract quality team players which is very important as the industry deals with the problem of the tight labour market (Zhou *et al.*, 2009a).

With the introduction of Building Information Modelling, 4D CAD challenges were removed and 4D modelling advanced gradually. Combining 4D modelling and BIM recognition of the building elements became possible. BIM also provided the automatic connection process between building components and construction schedules.

A 4D BIM has shown good potential as a starting point for planning progress and carrying out model based progress monitoring. However, the construction practices are still costly, with many errors and irregular completion. Researching the detections of the causes for these errors is in the plan model. The level of detail in the BIM model is not appropriate enough for following the progress on a component-by-component basis (Han and Golparvar-Fard, 2015a). Despite the fact, that this was pointed out no research fulfil this gap, and the level of detail remained to be an unexplored area in the AEC industry. This study was intrigued by the gaps in knowledge on the topic of the recognition of the LOD importance in construction progress tracking, and the lack of the researches regarding the problem.

The solution for comprehending collaborative 4D planning is in the collaborative planning workflow. Starting with a shared 3D model that is manageable by all designers, allows them to foster a collaborative scheduling session and continue work with multilevel communication. This interaction among planners allows them to perform their planning work. Using a 3D model as a start, everyone involved in the planning process is able to evaluate the design, discuss planning approaches with each other, and propose solutions. The fact is that 3D and 4D process synchronization has an immense impact on the project's outcome (Zhou *et al.*, 2009b).

3.1.1 Development

Monitoring and recording the progress of the project started in the early years of the 20th century with the Gantt chart development. However, tracking the progress of the construction project with the Gantt chart combined with network diagrams and flow charts does not provide communication and visualization of the project timeline.

Through the 1990s, a 4D CAD model was introduced to the project team to examine the effect of time and space during the building period (Aouad *et al.*, 2012h).

Koo and Fisher (2000) emphasized a 4D CAD's capability to visualize the improvement of the construction stage by connecting components of the work to the work tasks on the construction timetable. In 2002, Dawood *et al.* (2002) developed a database to accumulate construction information between construction activities and 3D components by Standard Classification Methods (Uniclass). In 2004, the development continued when Wang linked the structure's details with 3D CAD objects. As the 4D simulation is known for assisting in reducing waste in 2005, 4D technology was applied in the construction and resources management. The technology has its use in presenting designs to owners in order to encourage cooperative working (Kim *et al*., 2011a).

According to Heesom and Mahdjoubi (2004), 4D modelling can be used in solving problems with the site logistic "such as work execution space" (Heesom, 2004b). In 2007, Jongeling and Fisher promoted a location – based program technique which could be improved with a 4D CAD model to increase the work-flow onsite (Kim *et al.*, 2011b).

In 2008, Chin monitored the development of steel-work in multi-storey buildings by using 4D CAD and RFID (Aouad *et al.*, 2012i). In 2008, a 4D model was developed in the environment of geographic information system by Bansal and Pal. The following year, a 4D model was introduced as an as-planned model over time-lapsed photographs which had the purpose of monitoring the project progress.

In 2011, a 4D CAD applicability was considered in order to be used in facility management. The emergence of Building Information Modelling has remarkably improved the development of 4D CAD. With the growing acceptance of BIM in the AEC, the use of 4D CAD is becoming extensively encouraged (Kim *et al*., 2011c).

3.2 Existing standards and framework

In the construction project, the lack of information required for the decision making and maintaining the smooth running of the project is the biggest problem which was first pointed out by Winch (2010) who summarized the approach to the project management.

At the commencement period of a construction project, the result of the contraction project is a little more than an idea as at this stage the ambiguity is very high. How high the uncertainty could be depending upon a numerous aspects such as the degree to which the asset is a copy of the ones existing; the level to which consistent components and solutions can be used; and the range of the requirement for new technologies to solve the specific problems sat by the project. This might be equal as starting a mission and undertaking ambiguity inbuilt in the project. As the project develops, uncertainty is decreased as more information becomes available which provides for insignificances in design to be resolved.

In this research, all the discussion of the forgoing literature analysis comes back to the persistent information course as an issue. There is also the repeated question how the planning of project activities can be supported, and how the dynamic construction project can be greatly presented.

The degree of the unbalances at specific in the project cycle comparative previous and later points in the project life cycle could be considered as the level of dynamic uncertainty on the project (Winch, 2010a).

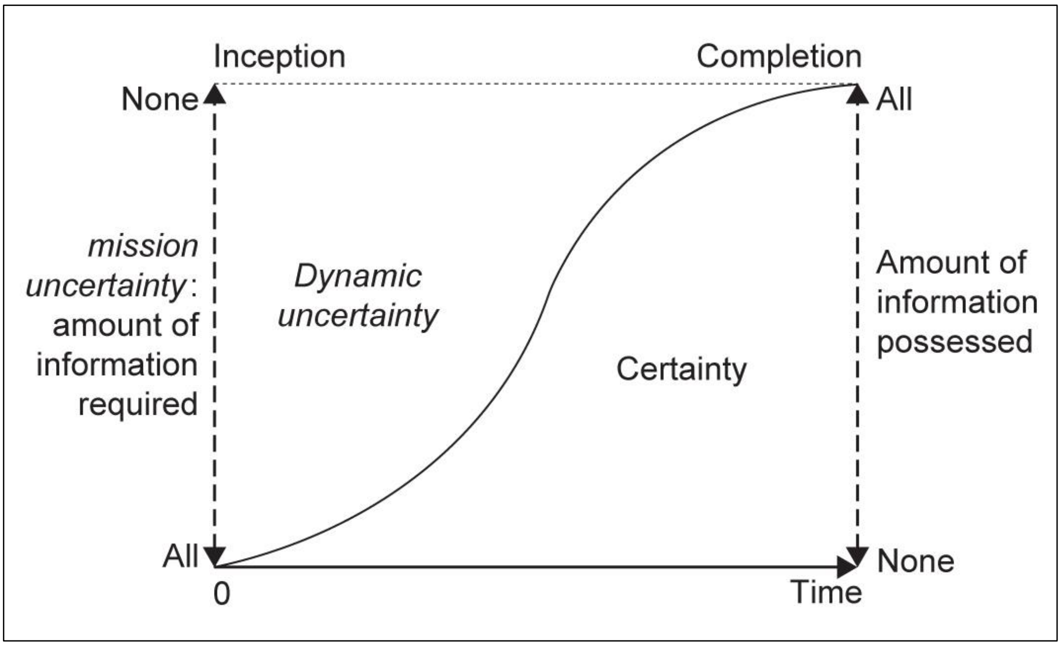

Figure 3.1: The project process as the dynamic reduction of uncertainty through time

(Source: Winch *et al.*, 1988)

According to Morris (1994), project management is about the entire process but not just about recognizing a requirement for time, cost and quality. Furthermore, he separates "the management of project" as a planned approach from "the project management" as a toolbox method for carrying the project operations. Construction projects bring together assets and human resources. There are also resources of equipment as well as components and materials supplied by firms outside the construction industry.

Usually the large number of different types of operatives and equipment is required for each project. The project team comes together sharing projects objectives in order for each team member to meet its individual objective (Winch, 2010b).

The progress level is where the project is executed through a flow of information which initiates and controls the movement of materials. It becomes impossible to keep all the data in the model. This would make the objects and later on the model overloaded. The connection to other interactive bases provides a broader source of information and empowers the object making it a rich source of information (Mordue *et al.*, 2016).

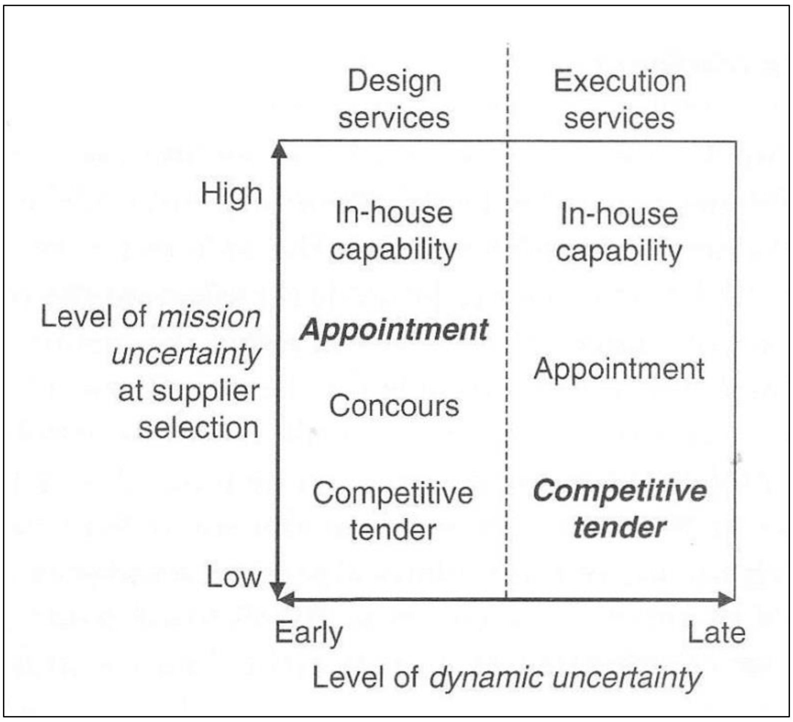

Figure 3.2: Supplier selection methods (methods in bold are the most common at each phase) (Source: Winch, 2010)

3.2.1 Project planning

This section provides justification and consumptions of project planning as a starting point for the construction project. The study takes into consideration various researches about the technologies, systems and processes to bring out the current knowledge and point out the knowledge gap.

When planning the construction project it is necessary to include the conception of an objective or facility as well as scope of work outlining the work product. The proposed package involves the plans and specifications creating the scope of work to be executed. To be appropriately accomplished the scope of work should be broken into components. The components outline work sections or building blocks which need to be completed to apprehend the end objective. Considering this the project is the synopsis of its sub-elements. Meaning of the sub-elements is important because it defines how the project is to be held in the field. The sub-elements are discussed as work packages (Winch, 2010c).

Levels of accuracy that are possible in the budget are usually seen through the appraisals of product breakdown structures (PBS) used for initial-stage budgetary planning and the work breakdown structure (WBS) used throughout the scheduling and implementation phases of the project (Winch, 2010d). As the construction project planning concentrates greatly on time and cost management planning this is a continuous task. The WBS method delivers an extended way to calculate, outline, measure and control the elements of a given work scope. Furthermore, in addition to time and cost planning a number of the planning efforts are required when construction a facility (Halpin and Senior, 2012).

Moreover, Hammer and Champy (1993) introduced the concept of reengineering an approach of necessary rethinking and drastic redesign of business process to achieve a significant increase forward rather than small constant gains. In other words, the reengineering is, in principle the operative management of essential change, when reorganizing the operations with a goal to increase productivity (McGeorge and Zou, 2013a).

The decrease of uncertainty from the beginning of project to the project end has an important effect on project budgets; it means that budget evaluations made early in the project life cycle are fairly imprecise compared to those made later as more data becomes available. More information is accessible for both the specific work to be done and the current market level of prices. Cost estimation is a progressive method through the project life cycle as more information is assimilated about the challenges of undertaking the project assignment and insecurity is gradually reduced through time.

The main reason for the separation of the contract for design from the implementation on the site is the high level of inaccuracy. The accuracy valuation may well be enhanced significantly through better data whether Building Cost Information Services (BCIS) or the very own database from previous projects.

The task duration is hard to be planned and it could be only assumed generally distributed around anticipated task delivery. Current estimations of anticipated task period are prolonged because they contain safety time, significantly extending the length of the critical path. However, when the task duration is uncertain the average estimate duration should be used in order to meet the deadline of construction projects. Releasing safety time from those performances the task, project managers are able to allocate it tactically and form some sort of shields to protect the critical chain. By uplifting the control this way, as a result the complete project period is reduced as long as the lengths of the calculated shields sum is less than total safety time. Additionally, the advantage is also seen in decreasing the impression of Parkinson's Law, which states that "work expands so as to fill the time available for its completion". When decreasing target time the outcome of Parkinson's Law is lessened for the half of tasks where the concrete interval is not as much than the estimated duration.

Space study points out that besides incorporating task execution for finalized structure it also includes temporal spaces in which tasks are to be executed. Task performance space accessibility is thus dynamo for the reason that different trades pass through the same space and possibly would clash at some point because the spaces themselves change throughout the project. The space planning problem in construction has two leading features that are co-dependent, but they need relatively different approaches. One is a scheduling problem, concentrated on the planning of task execution spaces. Second is the site layout problem, focused on the settling for temporary services of various kinds (Winch, 2010e).

Reducing task duration and providing execution of the tasks as efficiently as possible in a collaborative context is important for regaining the control by project managements who carry whole responsibilities of managements.

For efficiency, it is crucial the shielding task execution thus the next tasks only start when previous tasks have been completed and all the assets are available. Such ready to start tasks are identified as quality assignments. Using only quality assignments and managers can equally reduce cost through improved efficiency and decrease lengths by eliminating uncertainty. In cases where resource consumption is not reduced because of the interruptions in task commencement as an effect of shielding, managers are likely to build up buffer frameworks of quality assignments off the critical path, under which under full resources can be distributed.

The formation of quality assignments is the phase in the project planning process known as Last Planner. It is a cooperative method that takes in and empowers those who are directly in charge of supervising the work activities on the projects. This means that the Last Planner are the team members in control for making the final assignment of work to particular performers and they make certain the performers have the resources, equipment and information available to complete their assignments.

For the duration of the design phase, last planners are architectural and engineering projects managers, and for the period of the construction phase, last planners are usually foremen (Richert, 2017). The weekly design-making sequence can be located in the framework of look-ahead scheduling of a monthly or quarterly phase using critical chain (Winch, 2010f).

For this study, the learning outcome about Last Planner System is the metrics given in the percentage of weekly planned tasks that: were completed as planned, the percentage of the ready to begin as planned tasks and the number of tasks in weekly plans that were acknowledged in the look-ahead plan.

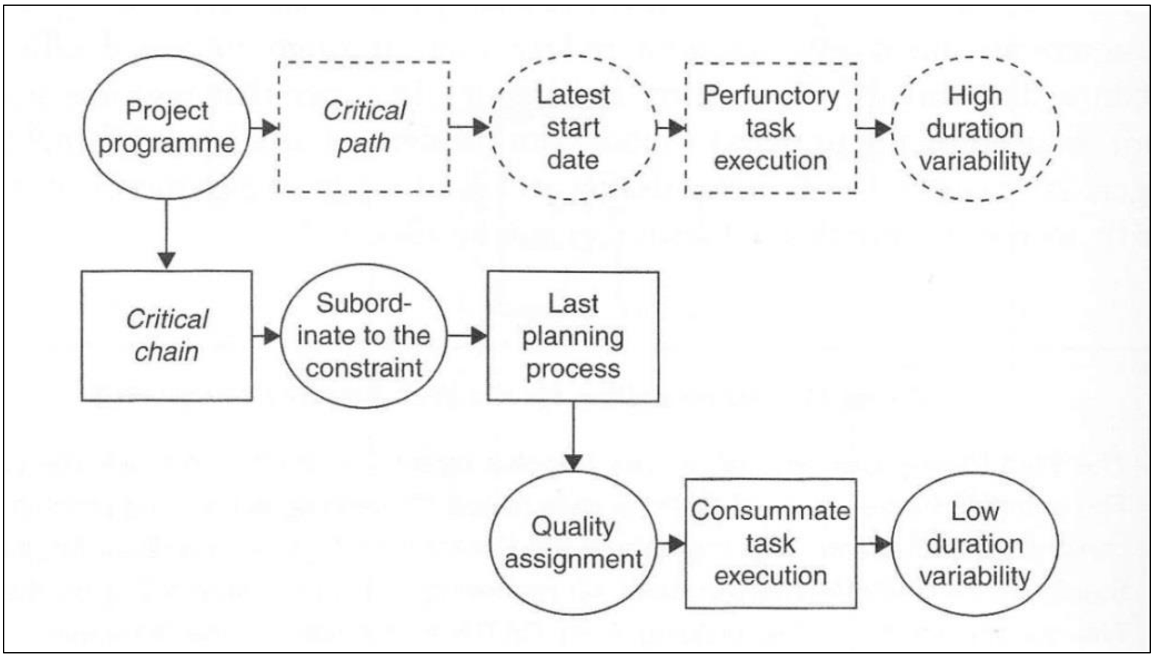

Figure 3.3: Last Planner and critical chain combined

(Source: Winch, 2010)

3.3 Technology for 4D and current applications

This section discusses the current technology for 4D modelling, its advantages and technology limitations. 4D modelling is supported with many software applications whether they are suite applications or stand-alone third-party application. Using suite applications for the project, the construction team is able to create the 3D and 4D models within one application family. In this instance, 3D elements are connected with time by either specifying detailed points within the modelling application, or by introducing a project schedule into the application. Creating the 3D model and 4D model within one application family prevents issues of data interoperability. When forming a 4D model, the 3D model is brought in together with the project schedule and the link is then made in this application.

3D CAD/BIM models have a precise layering arrangement within the 3D modelling application. As building of a structure always goes gradually and these 3D models are not typically designed for 4D modelling, the model designers need to have 3D model layering systems that support the 4D CAD activities (Aouad *et al.*, 2012j).

3D models have to be structured into work components to match the level of detail in the schedule. Geometric information has to be employed into different layers and CAD components reorganized onto different set layers. The next step is to break components into small pieces on different layers. Development of BIM models provided better exchanging of 3D items to a 4D model as the object order in a BIM model is clearer and more appropriate for a construction schedule.

For producing the construction schedule, it is necessary to name project activities as well as their duration, relationship between activities and their classification. The schedule level of detail given in 4D CAD modelling is insignificant for 4D visualization. As it is not possible to show all activities in the 4D visualization, it is worthwhile to classify the activities into different categories.

If the 3D model and the schedule are established appropriately the connecting of the two elements together to form the 4D CAD model should be a direct process. Lately some software applications have been technologically advanced and provide automated connecting based on the exclusive indicators defined in both 3D modelling and 4D modelling software.

During the construction development, the 3D design model and construction schedule have to be considered. Therefore, a 4D CAD model has to be updated as well. The project team might need to rearrange the 3D components, change the activity name, change the activity length or distribute and import the reviewed 3D model and relink the 3D object with the activities. It is still time-consuming task.

This study looks closer into the current market of 4D software in regard to see where the temporal and graphical level of detail stands for in each of the offered technology.

Bentley Navigator provides Project Wise Schedule Simulation for additional awareness of critical project schedule information by importing and connecting to schedule information accomplished in Microsoft Project, Excel or Primavera. Bentley Navigator software is able to group objects in regard to LOD graphical capabilities but not able to subdivide imported geometric objects within the software environment.

This application makes it possible to work in a 4D environment and explore different options. The user can construct the cost-effective and safe building settings by visualizing schedule information and 3D industrial models based on the project schedule data.

Autodesk Navisworks Suite software includes a part of the TimeLiner which adds 4D schedule simulation to Autodesk Navisworks Manage. It has the ability to change time between 4D state changes but not able to change temporal steps neither to have multiple steps during a simulation. When a 3D model is developed using Autodesk Revit, the file has to be exported to a Navisworks file.

While using the TimeLiner, it is possible to import the schedule from a variety of sources. This tool permits the user to join items in the model with tasks in the schedule and simulate the schedule displaying the result on the model. This action also shows the planned schedule in contrast to the actual schedule (Aouad *et al*., 2012k).

4D CAD Modelling software in Innovaya Visual Simulation combines BIM objects with planning activities to complete 4D construction preparation and constructability review. This tool successfully increases the project communication, synchronization and construction logistics scheduling. Visual 4D Simulation incorporates a very strong 3D appliance and particularly assessable intersection therefore it benefits, builds and improves task systems which provide the project time savings (Aouad *et al*., 2012l).

However, every construction company needs flexible solutions to support evading collision in time and space throughout the realization of a project. Therefore, they require comprehensible software to consider all stages of the future projects at the planning phase. This will help the company to foresee in advance any clash that may arise and complicate the project scenario.

3.3.1 Existing software tools for 4D BIM

As 4D has evolved and become more prolific through the increasing use of BIM technologies and subsequently 3D digital models, a range of software applications that support 4D modelling have come to market (Table 3.1). These are part of suite or stand-alone third party applications. The functionality of these tools varies however the core ability is the same whereby 3D components are linked with temporal data through either linking on an individual or group basis. Generally this is undertaken manually, however the functionality of these is evolving by allowing the link to be developed using more automated algorithms using the attribute based data attached to the 3D elements.

Table 3.1: Current 4D software applications

(Source: updated from Butkovic and Heesom, 2017)

Company / Tool	Description	Linkage	LOD capabilities	
			Temporal	Graphical
Bentley / ConstructSim Planner	Provides Project and analyse wise schedule simulation. Import 2D and 3D design files difference sources	Importing and connecting schedule information from Microsoft Project, Excel or Primavera. Reviewing interfaces (clashes) and viewing and analysing schedule simulations	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects but not able to subdivide imported geometric objects within the software environment
Autodesk / Navisworks	Supports various numbers of BIM formats and has overall very good visualization capabilities Permits the importation of schedules from a variety of sources	Supports manual and automatic linking to imported schedule data from variety of schedule applications Allows the user to join the items in the model with the tasks and simulate the schedule	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects but not able to subdivide imported geometric objects within the software environment
Innovaya / Visual Simulation	Combines BIM objects with planning activities to complete a 4D construction. Generates simulation of construction process	Increases the project communication, synchronization and logistic scheduling. Links 3D design data in DWG with Microsoft Project or Primavera	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects but not able to subdivide imported geometric objects within the software environment
Synchro Software Ltd. / Synchro PRO ** *(Note that Synchro was acquired by Bentley Systems in June 2018)*	New 4D tool with improved scheduling and project management	Covers risk and resource analyses features and include built in tools to visualize risk, buffering and recourse usage in addition to 4D visualization	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects Ability for geometric objects to be subdivided within the software environment
Elecosoft / Powerproject BIM	4D planning to combine 3D planning and scheduling linking the project plan and model together in one application.	Users are able to import the IFC models in the project plan with full 3D visual impact and to create milestones and baselines to simulate projects.	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects Ability for geometric objects to be subdivided within the software environment

Vico / Schedule Planner and 4D Player	Part of the Vico Office Suite providing the ability to run full simulations of the construction process including 4D and 5D	Uses Line of Balance planning to link to 3D geometric model	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects for link to LOB tasks but not able to subdivide imported geometric objects within the software environment
rib software / iTWO 4.0	5D cloud based enterprise platform that also encompasses the ability to include schedule data for 4D simulation	Import model and develop schedule of activities within the software.	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	N/A
ACCA Software (Italy) / usBIM.gantt	4D BIM project management with project management and scheduling 4D time simulation.	Allows project managers to assign a time-line related property to each components of the BIM model in IFC format in order to see the entire construction process in open formats.	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects for linking to tasks

As BIM evolves and more 4D tools appear to the market some the functionality of many appear to converge. The basic premise of linking 3D to schedule data is the same throughout all of the above. Many tools have both the ability to import schedule data from most prominent planning tools, but are also now providing the ability to generate construction schedules within the 4D software tool. The strengthening of this approach in the future may well see an increasing up take of the 4D paradigm as it will potentially remove the 'linking' stage in the development of 4D.

In addition, the ability to import a wider range of 3D geometric formats is becoming a key factor in the tools. Whilst it is acknowledged that most have the ability to import the IFC file format, the ability to import native, proprietary formats appears to be a key area of development. In addition, tools such as Vico have to ability to interact with the BIM Collaboration Format (*.bcf) file type.

With respect to the level of detail capabilities, all of the existing tools have the ability to change the time between state changes of the 4D simulation. These can range from using minutes, hours up to months or also provide the ability to show the progress of the task as a percentage of the time completed. However, this study has to put emphasis on the fact that the software currently used by the industry's 4D practitioners, have no capability to have multiple temporal state changes within a single 4D simulation session.

For example, in one complete session it is not possible to view progress on a daily basis, then switch to an hourly basis then to weekly basis. This would need to be undertaken as three separate simulations with manual intervention. All of the software tools have the ability to link multiple geometric objects to a single task, or indeed group the objects together and link to a task(s). However, not all of the tools have the ability to subdivide the geometric objects from within the 4D environment. This aspect is critical to developing a level of granularity and a subsequent higher level of detail for the simulation to show greater detail in the process of construction.

The reason for the commence of this study is the unexplored topic and gap in the literature regarding the non-existence of the suitable tool for the breakdown of the geometric object within 4D simulation. The higher level of detail in 4D setting and the possibility for the decomposition of the geometric objects need more attention.

3.3.2 Impact of Industry Foundation Classes (IFC)

A specific BIM format to represent building models in object-oriented database has been achieved with Industry Foundation Classes (IFC). This object-based file format established by buildingSMART includes detached and abstract building components. Building elements are members of classes, whether separate objects such as walls and windows, or nonfigurative elements such as project and process. Items in an IFC model are connected to each other through a multi-layered complex of relationships creating a graphic order.

There is a need for an open data model standard in the construction industry when temporary grouping is done for building projects as the compatible tools and quality and anticipated IFC has been present in a BIM process for more than ten years; however the use of the format between project actors has remained low. IFC-sustained model-created construction has the possibility to change the primary fundamental of the construction process.

The prospect for better productivity is significant: open interoperability for building information modelling would support the continuous flow of design, cost, planning, production and maintenance data decreasing unemployment and increasing productivity throughout the lifespan of the building (Laakso and Kiviniemi, 2012c).

3.3.3 4D CAD in practice

For this study, the extensive look into the use of 4D technology in current practice is significant to further justify the necessity for the standardization of the 4D LOD to enhance the 4D modelling creation and its trustworthy results.

The use of 4D CAD in AEC practices is seen in evaluating and visualizing many phases of the construction project. Users start with analyses of 3D design and the classification of construction then continue to the connections between schedule, cost and resources. The creating, updating and maintaining of a 4D CAD model is a process that lasts all the way through the construction project. Different views of the 4D CAD model can be created to accurately communicate the three-dimensional and fourth-dimensional data and progressive characteristics of construction schedules to all project contributors. This points out the importance of 4D CAD technologies, not only for animating the order of construction, but also for communicating an extension range of the project data in a clear and efficient way.

4D CAD tools could deliver a view of a combined project database. This database will incorporate and sustain the representation of building elements and all construction activities. It will also include their interrelationships and relations to the additional project data such as cost or materials. Its design will support parallel engineering of the structure and its delivery process by assisting numerous representations of a single set of the project data. Then, various presentations from different disciplines are necessary in order to access and interpret the data (Aouad *et al.*, 2012m).

Table 3.2: Analysis tables covering all aspects of 4D

No.	Author / Title	Topic	Description	Area for future improvement
1.	Han, K.K. and Golparvar-Fard, M. (2015) Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs **(in the US)**	Usage of time-lapse camera where images captured together with computer vision methods for developing new progress monitoring tool.	Method is promising high accuracies in appearance-based reasoning of construction progress as long as a point cloud model captures the entire site.	Decomposing BIM into detailed model to create sequence alternatives and develop details for construction. Create comprehensive Construction Material Library (CML).
2.	Heesom, D. (2006) Interactive Generation of 'Multi-Level of Detail' 4D CAD Simulation **(in the UK)**	Development of software tools to generate dynamic multi-temporal resolution 4D models.	The system targeted at the planner hub to allow the planner (designers) to keep control over the link of tasks, the specification of the LOD required and assisting semi-automated process of linking 4D.	Not fully automated. To improve the temporal LOD to accommodate work process to be developed and viewed in hourly work units.
3.	Boton, C., Kubicki, S. and Halin, G. (2013) Designing adapted visualization for collaborative 4D applications **(in Luxemburg and France)**	Method how to design adapted visualization in collaborative 4D applications.	How to compare the constructability of working methods to identify potential conflicts and clashes and improve monitoring of the progress of projects.	Needs for the adaption of the visualization for the business needs practitioners. nD view coordination mechanism to be evaluated and consolidated in future works.

4.	Moon, H., Dawood, N. and Kang, L. (2014) Development of workspace conflict visualization system using 4D object of work schedule **(in Korea)**	Method how to minimize overlap period work space for activities that may be conflicting. This would increase work productivity and reduce accidents at the work sites.	To generate workspace using automated bounding box model (in 3D graphics) and an algorithm to identify workspace conflicts within a 4D simulator.	System does not have automated rescheduling function to minimize conflict. Needs for generic algorithm method that can create an optimized schedule with minimized conflict ration.
5.	Trebbe, M., Hartmann, T. and Andre, A. (2015) 4D CAD models to support the coordination of construction activities between contractors **(in the Netherlands)**	Method how to enable co-builders to visually identify conflicts between different work tasks.	Usage of 4D CAD models in pre-planning stage identified easy conflicts between the different construction engineering designs, schedules and planning operations and mitigated conflicts before they led to costly changes during construction work.	Need for exploring the limits of applicability of 4D CAD models.
6.	Trani, M.L., Cassano, M., Todaro, D. and Bossi, B. (2015) BIM level of detail for construction site design **(in Italy)**	Method how to develop Construction Site Information Model (CoSIM) by using an inventory of BIM elements in 3D models.	Sharing and visualizing site information from pre-design stage. It reduces the time-waste of activities up to end of executive stage of works.	Needs to improve current weakness on site equipment real product BIM object. More development of CoSIM.

7.	Zhou, W., Heesom, D. and Tah, J.H.M. (2014) User-centred design for collaborative 4D modelling **(in the UK)**	General needs for collaborative BIM applications can be identified using the guidance from CSCW (Computer-supported collaborative work) theories.	The method could benefit modelling common use in BIM like cost analysis, sustainable design, facility management and others.	Improvement in lack of awareness of design participants / parties for smooth task transition in projects.
8.	Sacks, R., Whyte, J., Swissa, D., Raviv, G., Zhou, W. and Shapira, A. (2015) Safety by design: dialogues between designers and builders using virtual reality **(in Israel and the UK)**	Consultation and dialogue among designers and construction professionals are beneficial for the safety aspect of every design where designers are willing to adopt design details to enhance the safety during construction.	Various safety issues became much clear to designers after dialogue and site demonstration using virtual reality.	Improvement in various construction policy regulation as: collective safety responsibility including designers; preparation of construction safety plan through collaborative works of design and construction team; designer to obtain forms on construction safety.
9.	Abrishami, S., Goulding, J., Rahimian., F.P. and Ganah, A. (2015) Virtual generative BIM workspace for maximising AEC conceptual design innovation **(in the UK)**	Optimal solution for conceptual design automation in BIM support for construction.	Development of an interactive BIM generative design as method for computational design for initial stage of architectural design. The method provides techniques for exploring and generating design solution; create models with information needed for development process and create generative process which can control outcomes.	Further studies are needed to develop and validate this generative design concept using domain experts and focus groups to further refine the model.

10.	Wang, J., Wang, X., Shou., W. and Xu, B. (2014) Integrating BIM and augmented reality for interactive architectural visualisation **(in Australia)**	New approach to enhance architectural visualization in building life cycle as support to BIM and AR (Augmented Reality).	The system demonstrates performance which allows interaction between owners and designers by using virtual building scheme in physical environment by merging BIM & AR tool.	Improvement in quality and stability of AR supporting scenes as property marketing module.
11	Kensek, K. and Kahn, W. (2013) Integration of Environmental Sensors with BIM **(in the US)**	Case studies to demonstrate possibility of connecting environmental sensors with BIM and confirming that the process could go from real to virtual models and from digital to physical models.	Creating various models using and combining different programs where Dynamo was in most of cases used as an interlink to Arduino board through Revit BIM.	Dynamo slow speed interaction with the database. Geometry produced from Dynamo workflow are easily accessible for adjustments, manipulation and to be deleted directly in the Revit interface.

3.3.4 4D CAD models in the project lifecycle

The use of a 4D CAD all the way through the facility lifespan proves the effectiveness of the fourth-dimensional models in the construction management.

Starting with the planning stage, the 4D model can be used to define different phasing arrangements and site formations or to enhance the construction schedule. These prototypes allow the evaluation of different options with detailed valuation at quite a low cost to the design team and the client.

A 4D CAD benefits design and pre-construction by improving build capacity of the design and the adjustment of the gains of different construction stages. The 4D models can be used to improve the stages in the construction schedule. Additionally, the models can be used as visualized information to the client for his better understanding of the design in the pre-construction phase.

In the construction phase, a 4D CAD can be used as sequential phases of construction, synchronization and build capability. During the construction phase, the 4D CAD also shows the work of subcontractors, considerate traffic and site-flow processes. Onsite 4D models can be used for systematic construction advancement analyses. In addition, these models can be used to assess similarities and differences between as-built and as-planned schedules for management and evaluation purposes.

The use of 4D models for reviewing progress and construction changes during the construction project improves the relationship between the client and construction team. A 4D CAD shows significant benefits in renovation projects as well. The model can be used to communicate the services and control system changes needed for the specific period during the renovation project (Aouad *et al*., 2012n).

3.3.5 4D CAD advantages

The 4D technology with the capability of attaching time data to the passive 3D model has a huge influence on the project execution. The construction players are able to observe construction improvements or schedules in a 4D environment. A 4D visualization implementation can make the entire construction development evident in a detailed way and show possible struggles in a construction site. The possibility of “what if” exploration can be worked out to evaluate and compare a number of planning options in order to come up with the best idea (Aouad *et al*., 2012o):

Advantages of 4D modelling currently found in construction practices are:

- Improved participants communication through visualization and improved understanding of proposed design.
- The elimination of field interventions as the analysis of site, building steps, construction undertaking and site alignment is possible.
- Assists the progress of construction categorization thereby reducing the rework.

- Provides better budget control.
- Increases productivity
- Reduces the change orders during construction
- Reduction in time from the beginning of construction to facility turnover.
- Improves safety management on site

3.3.6 Technology limitations

Even though 4D modelling has been recognized as technology with clear advantages during the design and construction process, a number of weaknesses have been noticed when carrying out this technology during the construction project. Limitations of 4D modelling are (Aouad *et al.*, 2012p):

- The need for two or more software applications in order to integrate design and planning information.
- The absence of construction plan information as the construction activities could not all be visually presented.
- No clear evaluation and duration of activities in the project.
- Persistent need for the Gantt chart to present activities' relationships
- The project team still have to modify or optimize the schedule manually for a 4D model in order to completely recognize its benefits.
- Lack of more dynamic 4D simulation in order to achieve more reliable outcomes

Absence of appropriate level of detail in 4D models was pointed out by Heesom and Mahdjoubi in 2003 when they were evaluating the construction process by using 4D models. They concluded that developing more dynamic 4D simulations would provide more realistic simulation and more accurate results. However, for more than a decade this issue has not been addressed (Heesom, 2006b).

3.4 The role of Level of Detail (LOD)

This study looks close into the level of detail role, for the reason that LOD is a crucial component of the certainty that can be placed on the information required for the project efficiency. It provides development from a simple design to a virtual construction model. This study discusses the non-compliancy of different levels of detail.

The professionals in the AEC industry understand the concept of the virtual model, yet simply starting virtual modelling as a requirement has produced confusion and obstruction. This raised the need to outline the levels of virtual modelling, generally stated as the level of development (LODt). The level of development describes the accuracy of the 3D components and the quantity of information contained by each component. Level of Detail essentially defines model evolution (Bedrick, 2013a).

It should be mentioned that the introduction to the use of LOD in real-time 3D graphics was researched for the first time by Clark (1976) the computer programmer at the University of California (Luebke *et al*., 2003a). In his paper "Hierarchical Geometric Models for Visible Surface Algorithms" published in 1976, Clark arranged the basic codes behind the level of detail (Clark, 1976). Many progressive topics in the existing LOD research were first raised in his paper, as well as keeping a graphical working set in instant-access store, or what is known as simplification and rendering, perceptual metrics and parallel processing of scene graphics for LOD (Luebke *et al*., 2003b).

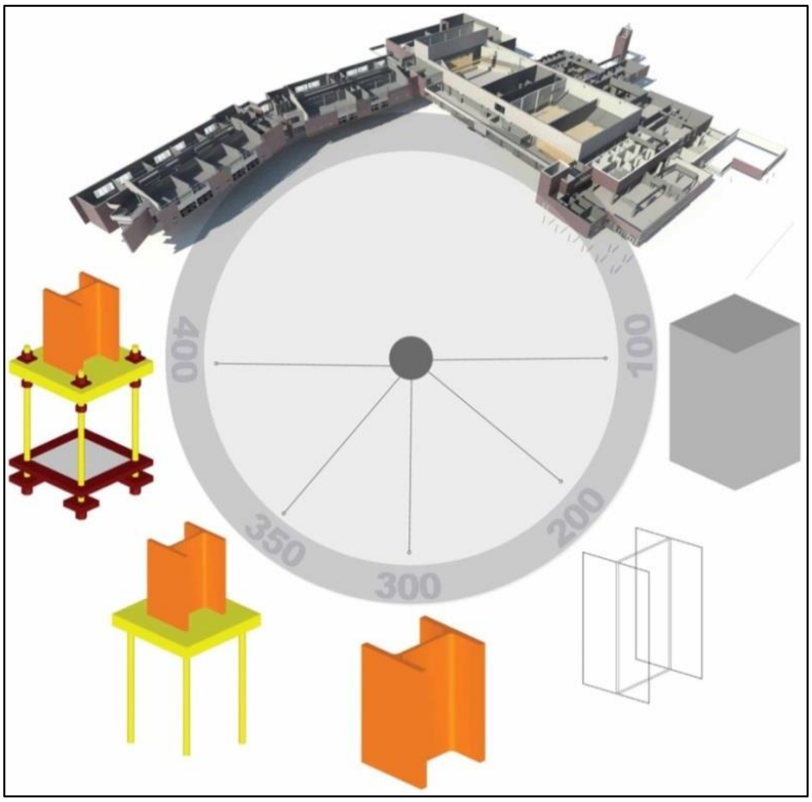

Figure 3.4: Using LODt to model the structural column

(Source: BIMForum, 2013)

Moreover, the consistent use of the LOD concept increases its effectiveness as a foundation for collaboration. The LOD framework was developed as an agreement-based standard to be useful for outlining, at the assembly and element level, the consistency of information confined in BIM. The Level of Development Specification is the document that allows AEC experts to identify and articulate, with a high level of precision, the content and reliability of BIM at different phases in the design and construction process.

The LODt Specification provides characteristics of model elements signifying building systems, assemblies and elements at different LODs. With this clarification, it is more understandable what the model can be relied on for. In addition, the document allows downstream users to clearly identify the usability and the limits of models they obtain (Bedrick, 2013b).

This specification permits both temporary and final models to be completely and clearly outlined. For any BIM effort, this allows the generation of advanced significance deliverables. The LODt specification improves planning and tracking, precise and reasonable scoping and pricing of modelling effort. The designed models are more reliable and they can be used for many purposes, to improve productivity and substantial cost savings (Bedrick, 2013c).

3.4.1 LOD in BIM

This research found out that the main motive for the current increase in the utilization of BIM within the AEC/FM is that BIM improves project performance, interoperability and processes. Furthermore, during the research it has been acknowledged as the project planning is crucial for using BIM in a project, it is vital to identify what to include in BIM to succeed through BIM usage. The level of detail to be included is a critical principal to think through while developing a BIM project. Thus far, many researchers have indicated that the cost of estimating and generating fabrication drawings and energy simulation are dictated by the LOD of the model (Leite *et al.*, 2011).

In addition, some researchers consider that, depending on the BIM practice, various types of BIM need to be created, particularly different cost models, equipment inventory models, sequencing models, coordination models or construction models. However, LOD in BIM is defined based on elements and the progression of the elements all through the project from the lowest level approximation (conception design) to the highest level of the representation (as-built).

The American Institution of Architects (AIA) has been developing principles to assist communication during the construction project. AIA E202 is a document providing guiding principles about the models indicating the relationship of the level of development with the proposed use of the model at every stage of the project (Kensek, 2014a).

Approximate LOD signifies components as basic elements with the absence of major specific properties as will be shown in the confirmed final drawings.

3.4.1 Decomposition in building design

As earlier indicated in this study, Hammer and Champy (1993) introduced the concept of reengineering as a drastic redesign of business processes. The last planner concept is a bottom-up reengineering method concentrating on the production development rather than the systems. The “last planner” needs the automated concept of reengineering. This comprises of the technological application for the revision of existing systems, processes and products in order to make them more operative, competent and approachable. The understanding of complex models could be aided by the technique of model decomposition that subdivides models into smaller significant sub-models in order its conception. (McGeorge and Zou, 2013b).

For this study, model decomposition is important because this method can be used for the development of detailed computer simulations possible to change geometry.

Components are essential for the decomposition as they are an interpretation of the architectural draft that optimizing the model. These components assist in defining the design as a system to which analysis is relevant. The breakdown of architectural design into sections on components and decomposition into an object-oriented system could be achieved with existing standards for BIM that allows analysis and optimization which is known as Industry Foundation Classes (IFC). However, the existing IFC standards mainly serve for data exchange thus its existing structure need extensions (Geyer, 2009a).

A design has norms that can be stated numerically and also qualities that cannot be expressed numerically. Examples such as appearance, aesthetics and function. The non-numerical characters eliminate the possibility to be evaluated effectively by numerical analysis methods and accordingly by optimizing algorithm. As the designer is able to evaluate aesthetic or functional characteristics very well he should be the one to manage these aspects. The designer can do the calculation by connecting between the model elements and allowable alternations such as parameter changes or system alternatives.

Each model includes limits concerning the potential solutions and therefore eliminates other solutions from being reached in the design space. This limited set of values for the design Grierson and Khajehpour called implicit constraints. As a result, all limits initiated by the structure of the model together with enumerations for parameters, are implicit constraints. Each structure of a model indirectly favours and dismisses certain design in the solution space. For example, the setup of the frame-based design excludes a grillage design and thus the different design ideas lead to different structures of the same model system.

The two optimization models have their own independent design variables although both models belong to the same design space. The chosen way of the model set up would depend on the architectural design idea for the construction (Geyer, 2009b).

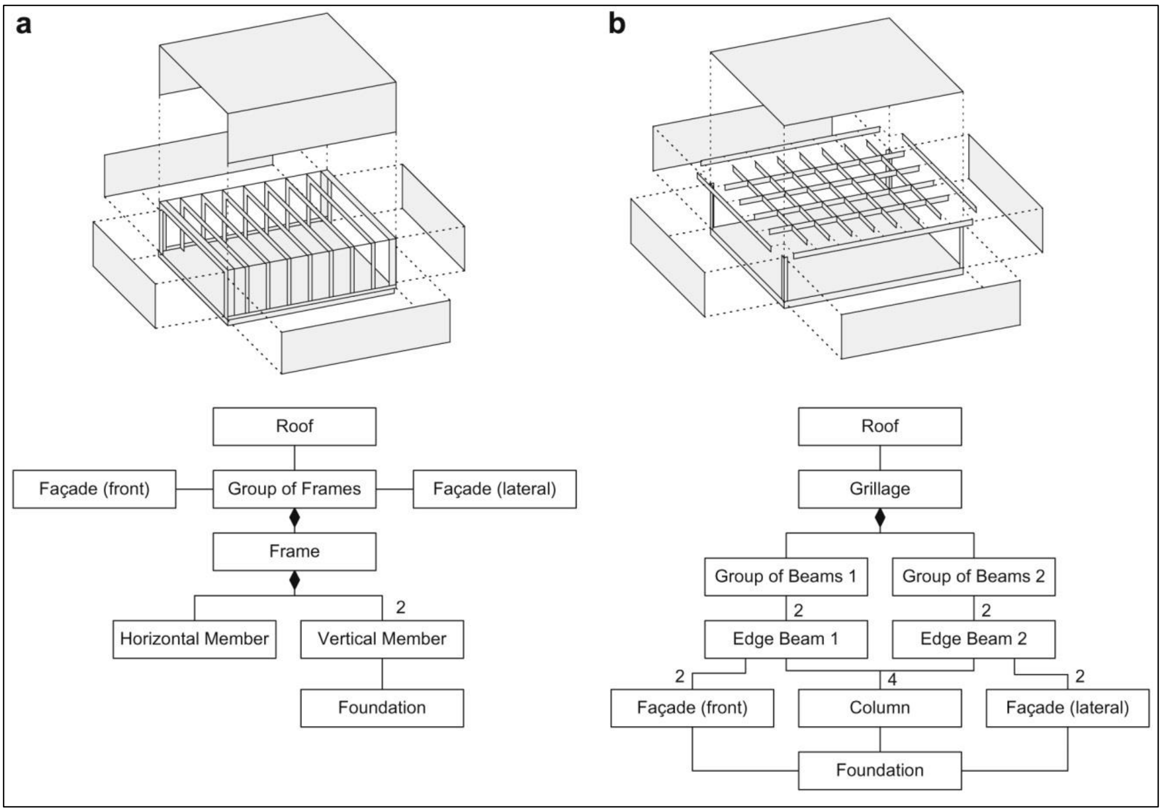

Figure 3.5: The structure of the model sets implicit constraints. Two alternative structures incorporate different aesthetic ideas of the construction: (a) a frame based design and (b) a design using four fixed columns with a grillage as roof structure.

(Source: Geyer, 2009)

Setting the structure of the model is a vital part of the design process. Thus a swift development of setup within a CAD-integrated environment is necessary in order to be able to collect a related result for each design alternative. In the CAD environment the designer creates the geometrical and graphical characteristics of the design whereas the basic analysis and optimization demonstrate the numerical part. This technique permits a balance between different design ideas and their differences in relation to numerical assets on the one hand and aesthetic attributes on the other (Geyer, 2009c).

3.4.2 Model-based coordination

The BIM process begins with the model-based coordination; it is the initial use of BIM. Document coordination and installation coordination are crucial for providing better structure and quality and causing fewer issues during construction and during operation. (Hardin and McCool, 2015c).

By learning how to use BIM's advantages, these two synchronization processes can be brought into line, but doing so requires understanding of the LODt and preparation of the team (Hardin and McCool, 2015d).

From LOD 100 to LOD 500, the clear development for the geometric representation, probable prevision and presence of related data is defined. Essentially the standard classifies the level of development, not the level of geometric complexity of the object.

LOD 100: The element can be characterized by a symbol or other nonspecific description. This type of data can provide only conceptual analyses. For instance, when the designer creates nonspecific masses for program components in the building, he can define room areas, estimate dimensions and sectors and link spreadsheets with architectural databases on square footage. The estimation of the conceptual cost analysis and the total time of the project construction are also possible.

LOD 200-400: The model element is generated as an object. The object includes characteristics that are nongraphic data. Graphic progress from LOD 200 to LOD 400 is concerned with the precision of the geometry of the object in relations to quantity, size, shape position and coordination. Quality data will possibly contain items like cost (from approximate to real cost) scheduling information, manufacturer and so on.

LOD 500: The model element has been field confirmed in relation to its geometry, and contains characteristics such as specifications and product data in order to support operation and maintenance of the facility (Kensek, 2014b).

3.4.3 LOD in 4D modelling

4D modelling has been a research area for around two decades and the main conclusion of research projects highlight that effective planning is one of the most important aspects for successful project execution. Additionally, it is indicated that the use of a 4D CAD is concentrated on aesthetic visualization purposes. Due to emerging research development in 4D planning, focus is now directed at the usefulness of 4D technology for various applications. Linking building activities in planning to 3D objects in a construction model, 4D simulation is used to simulate the building progression over time. 4D modelling found a huge role in evaluating the design and its constructability in addition to construction planning and monitoring. Nevertheless, the quantity of detail required in a 4D simulation is still unclear and the acceptance level of 4D simulation by the AEC industry remains low. It is necessary to indicate that this technology still has to be adapted to the industry needs as there are insufficient responses from experiments on regular projects (Boton *et al*., 2015***a***a).

This thesis addresses the research issues associated with the level of detail and how it can be managed the correspondence between the graphical and temporal level of detail in 4D environment.

The level of detail of the information included in BIM has to fit to the anticipated 4D usage executed by practitioners. This is a difficult topic because 4D simulations integrate both 3D components and construction activities schedules. These construction accomplishments in projects are usually produced by different stakeholders in unsynchronised processes. Therefore, the BIM level of development incorporates geometry and non-graphical information. For that reason, a 4D LOD requirement must manage both the graphical level of details and the temporal level of information.

3.4.3.1 4D and Level of Detail

The use of 4D adoption is increasing within the construction sector with upper management beginning to see the potential benefits of using it as a viable planning tool (Gledson, 2015). Issues of LOD around the 3D geometric model during design and construction have received attention both from practitioners and researchers. However, even with a great deal of attention, Grytting *et al*. (2017) noted that there were still issues to be resolved as a number of models were delivered with a higher or lower LOD than necessary leading to change orders.

Whilst the LOD protocols for the design model provides guidance to those interacting with the 3D geometric aspect of the final design, there has been little work presented to fully understand and define the specific level of graphical and temporal detail required for 4D simulations throughout the construction process. As such the LOD for 4D is still not well defined nor is the way to develop a simulation with a specific approach to LOD management (Guevremont and Hammad, 2018a).

The importance and justification of this research could be seen in the revelation of all the gaps in the literature regarding the inadequate information around the required 4D LOD for greatly successful simulation of the construction project.

Both the graphical and temporal detail of a 4D simulation must be such that it can facilitate effective managerial decisions and thus construction processes during the project (Guevremont and Hammad, 2018b). Furthermore in order for a 4D simulation to remain useful throughout the duration of a construction project, it must be continually used, evaluated and refined as the project progresses (Umar *et al*., 2015). This continued maintenance of the 4D simulation is subsequently seen as a limitation to the implementation of 4D during the construction process (Romigh *et al*., 2017).

According to Aouad (2012), in order to assist more dynamic 4D, the 3D model creators need to have approached the geometric composition in such as way that it can support the 4D activities and 3D models have to be organized into work components to match the level of detail in the schedule. However, in many cases the initial design model is often not created with the intention for it to be used for planning or control purposes and often leads to the contractor generating a new model for the purpose of developing a 4D simulation.

It is at this point that they may consider the LOD required to produce a viable 4D model, subsequently updating the representation of geometric objects (Liu and Li, 2013). As part of this process the granularity of the geometry of the 4D simulation can require either the subdivision of elements or the aggregation of elements to create the geometric portion of a '4D Object'. As early as 2008, Tulke *et al*. (2008) proposed an algorithm based approach to split geometric objects within an IFC file into portions away from the BIM/CAD authoring tool for the creation of more dynamic representations of construction within the 4D software environment.

This is now a more commonplace capability in some commercial tools, as is the ability to combine individual elements to create an aggregated group for linking. This variable approach of linking objects provides the ability to better satisfy any 4D LOD requirements (Guevremont and Hammad, 2018c). However, there is still an explicit link between the LOD of the BIM geometry and the requirements of the 4D LOD. For example, to facilitate the visualization of a high schedule LOD, a highly detailed geometric model may be required. A typical example would be a 4D showing the installation of cable trays where installation of individual hangers was to be shown. These geometric objects would need to be modelled in the BIM to be available to inclusion in the 4D simulation.

Boton *et al*. (2015***a***b) presented a case study of the development of 4D models at different stages of the design and construction process. However, the development of the Level of Detail within this project was mainly focused on the graphical detail of the design model. Models were created in accordance with the AIA LOD 100-500 series using a range of software tools and then 4D simulations were created. The work did highlight the changes required for the resolution of the plan at each stage and this was appropriate for the detail of the graphical model, also noting that LOD required for the construction phase is higher than the LOD needed in the pre-construction phase (Kriphal and Grilo, 2012a).

On the other hand, it did not resolve the critical question of decomposition of construction product elements for the generation of more dynamic 4D models and whether this is also required to change to meet the needs of project planning through the various phases of the lifecycle of the design and construction. The study did conclude that a single graphical LOD is not adequate during the construction phase and that different levels of development were needed for visualization and coordination, depending on the 4D model purpose and the specific construction problems that occurred during construction and modelling processes.

This view is supported by McGeorge and Zou (2013) who note the understanding of complex models could be aided by the technique of model decomposition that subdivides models into smaller significant sub-models in order of their conception.

It is apparent that in 4D models, LOD specification should manage graphical levels of detail and the temporal level of information in order to deliver realistic and more reliable 4D simulations (Tolmer *et al.*, 2015a). This is something that was successfully implemented by Guevremont and Hammad (2018) where two 4D simulations were implemented on a case study project. The low LOD was based on low schedule detail and the higher includes more detailed schedules and more detailed geometric breakdowns.

A medium LOD could also be used for workspace allocation. The work also notes the important issues of the time step used in the 4D simulation and this is based on data available in the schedule LOD and the ability to change between the low and high level of detail as required. This becomes a critical issue for 4D simulations moving forward as the ability to step between multiple LODs' within the same simulation session will provide a more comprehensive usability.

The absence of an approach to define and specify the level of detail in 4D simulations for effective evaluation of the construction process was highlighted by Heesom and Mahdjoubi (2003). They indicated that developing more dynamic 4D simulations would provide more accurate and more realistic outcomes (Heesom, 2006c).

In order to provide a more dynamic 4D simulation, the Level of Detail of the 4D simulation (herein termed LOD_{4d}) must manage both the graphical level of detail (herein termed LOD_g) and the temporal level of information (herein termed LOD_{ti}). The LOD_g is key to providing the end user with enough graphical information of the element due to be constructed. As an example, Han and Golparvar-Fard (2015) suggest that the lack of detail in the 3D BIM used during the pre-construction planning phase is not sufficient enough for tracking the progress on individual element bases but can provide an overview of the process.

In addition to the detail of the graphical element, the LOD_g also needs to encompass the granularity of the object(s) being simulated. In this case the granularity is defined as how a single 3D geometric BIM object is potentially sub-divided into constituent parts or aggregated for linking to individual tasks in the 4D simulation, providing a more accurate reflection of the dynamics of construction sequence. The LOD_{ti} within a 4D simulation is a critical factor as this details the planning horizon used and then the time period between state changes in the simulation required for each task i.e. 1 day, 1 week, etc.

Further comprehension of the interrelationship between these factors will allow specification for elements within the construction process. Moreover, although recognizing the importance of the graphical and temporal level of detail in 4D modelling, the available literature has few case studies on 4D LOD.

Table 3.3: Analysis tables covering LOD aspects

No.	Author / Title	Topic	Description	Area for future improvement
1.	Heesom, D. (2006) Interactive Generation of 'Multi-Level of Detail' 4D CAD Simulation **(in the UK)**	No change (part of program)	Fix LOD	Automated
2.	Boton, C., Kubicki, S. and Halin, G. (2015***a***) The challenge of level of development in 4D/BIM simulation across AEC project lifecycle. A case study **(in Canada, Luxembourg and France)**	Usage of different LOD (LOD200-LOD400)	Project breakdown structure elements were not at the same LOD as 3D models elements	To standardized 4D LOD To work on 4D LOD specifications, including temporal LOD description and relation between temporal and existing graphical LOD in BIM
3.	Tolmer, C.E., Castaing, C., Morand, D. and Diab, Y. (2015) Information management for linear infrastructure projects: conceptual model integrating Level of Detail and Level of Development **(in France)**	N/A (no G-LOD)	N/A (no T-LOD)	To reduce inconsistence between actual standards and LOD

3.4.3.2 Related works and methodology world wide

4D simulation case studies have been using different approaches to this technology. In 2002, Dawood completed his work on two case studies regarding Man Hours input required to run the model prototype. He concluded that the amount of work in one hour by one person increases according to accessibility of design information.

Hartmann (2011) described an ethnographic-action investigation on the safe development of a hospital renovation based on 4D models. He suggested a procedure to develop a hospital construction process creating a 4D simulation. Olde Scholtenhuis and Hartmann (2014) repeated the research experiment using the same ethnographic-action method. They examined the effect of scheduling purpose changes on the 4D-model layout by observing the frequent repetition of practitioners' implementation and the use of a real life 4D model. An outcome was that they became aware of recognizing tasks, allocating assets and communicating among stakeholders being crucial at planning phase. Construction planning, reviewing needs between tasks and improving procedures on schedule as planned are the main focuses of jobsites scheduling (Boton *et al.*, 2015***b***a).

Furthermore, the literature includes the 4D simulation research project for supporting the workplace conflict analysis, path analysis model, construction quality check-up and fall hazard identification. Although all the executed research and studies are informative and provide scientific facts about 4D technology development, thus far, only a few research projects have focused on the requirement of "LOD" for describing the content of 4D models. For instance, Koo and Fisher (2000) distinguished that 4D models provide an exceptional outlook of the project namely connected to scheduling, with a dedicated LOD.

In their opinion, it does not enable the involvement of numerous project participants to use the 4D model for other needs and to be able to generate models with different LOD, for the purpose of quick exploration of different possibilities. More recently, Boton clarified a framework appropriate for the design of 4D visualization. He recorded the description of a "collaborative situation" and the "informational needs" of a given professional. This method clearly conveys the content expected in 4D visualization for a given situation of use, and is appropriate when designing visualization techniques, for example software development (Boton *et al.*, 2015***b***b).

3.4.3.3 Analyses for 4D modelling

During any project implementation, the procedure for monitoring and measuring the progress became absolutely necessary for the project control. The current practises for control actions are still costly and error-prone and not constantly reliable. In recent years, researchers focused on the process of the laser scanning but the method was often influenced by 4D BIM as a baseline for planning progress and used as model-based progress modelling.

Operation-level progress (Han and Golparvar-Fard, 2015b):

- Lack of detail in plan model: LOD in BIM used for the pre-construction purpose in projects are not sufficient enough for tracking the progress on individual element bases. LOD300-400 is similar to less detailed models than traditional construction documents.
- Time-lapse images are collected from fixed camera viewpoints to record the work in progress and compare with one another or against 4D BIM. Colour-coding methods are used to recognize progress changes. Image-based material recognition methods are focused on the problem of construction material classification from site imagery. Despite the extensive usage of the image-based material recognition method, automatically analysing time-lapse images is still a challenging process as the object resolution of image patches is still insufficiently low.

There was a need in pre-construction stages of projects to compare constructability of working methods and identify potential conflicts and to use 4D models to monitor progress of the projects. The first component was based on the case study on the real construction site using a 3D model (SketchUp); D-Studio's 4D Virutal Builder and identified visualization needs at the site, while the second part of the study consisted of an online survey where the questionnaire was distributed to various professionals (practitioners and researchers) in the construction industry (Boton *et al.*, 2015***b***c).

In order to perform efficient work, there is a need to reduce workspace to minimum. This paper presents a methodology of how to create a workspace bounding box concept in 3D graphics to make efficient design for simplifying the creation of a workspace model that enables users to check automatically for physical conflicts between activities. A practical case study was conducted on the bridge project in Korea and was used in this paper (Moon *et al.*, 2014).

The case study chosen was a train station renovation project in the Netherlands. The study provides an explanation of how 4D CAD models help different co-builders in construction projects to align tasks in different construction engineering designs, schedules and operations. The study shows how 4D CAD can be used to understand complex interconnections between different stages of construction work in any project (Trebbe *et al.*, 2015).

The target of this study was to identify and develop standard design a BIM- based method and create a Construction Site Information Model (CoSIM). It is important to stub-divide pre-design and construction site activities into Preliminary, Definitive and Executive levels. A case study was conducted on the ABC Department in Milan which covers demolition of buildings, site organization and construction. The elements from Pre-design site BIM objects are added into the pre-design level presenting a Graphical level of details. In the case study it shows how the level of graphical detail changes from one stage to another (pre-design to executive) (Trani *et al.*, 2015).

The challenges of dynamic information exchange in projects are affecting projects delivery. Different specialised teams are performing their own programs which could be independent but interrelated and usually cause conflicts during the construction period. 4D modelling techniques can simulate the construction process and identify potential conflicts in construction plans. The technique can be generated in a computer dynamic 3D construction process with a time progressing component which allows 4D modelling to disclose hidden conflicts and enable an update and amendment of construction plans (Zhou *et al.*, 2014a).

This research pointed out in previous chapters the importance of the flowing information exchange where the unbroken chain of recorded project activities would provide smooth project delivery.

Currently, there is still, in the contracting industry a dominance of 2D drawings and documentation instead 3D-based digital models. There are no market-pull issues like requirements from designers or contractors to lead inventions of collaborative 4D modelling application. The interactive definition method is a collaborative 4D modelling approach with the main objective of creating collaborative working contexts for 4D development. The method requires specific 3D building models and can conduct three-level interactions.

Interactive definition method and CSCW (computer supported collaborative work) design dimension could consist of a series of collaborative work as: co-talk; co-sort; co-plan; co-simulate and co-navigate. Model based collaborative 4D modelling software can re-establish the missing link among dispersed planners in order to obtain complex construction plans through simulation. UCD (User-centred design) theories technique provided all practitioners with flexible options for designing and evaluating the selection of the right methods in coaching and design approaches as the parallel and iterative design combination are key for successful design (Zhou *et al*., 2014b).

Consultation and dialogue among designers and construction professionals are beneficial for the safety aspect of every design where designers are willing to adopt design details to enhance safety during construction. The CAVE experiment with 10 designers was used to explore designers' attitudes and knowledge and the possibility of learning and collaborating with the builders within a virtual construction site (Sacks *et al.,* 2015)

This research enables the automation of the conceptual architectural design process using BIM as a central hub for integrating all building design and collaboration using new techniques and systems during the design process. This is a research support mechanism for combining different concepts into a single generative design BIM concept. G-BIM framework is developed during the design preparatory stage where data files will specify the design constraints and context with minimum dimensions and details which are capable of providing techniques for exploring and generating design solutions (Abrishami, 2015).

The study is related to the new approach to enhance architectural visualization in building life cycle which can support BIM and augmented reality (AR) (Wang *et al.*, 2014a).

The method of research was focussing on four case studies and interviews. The process included the integration of BIM and AR as two different types of visualization techniques with four stages of building life cycle. The approach of linking BIM with AR could be described in three major components: BIM model, Data Transformation and AR platform (Wang *et al.*, 2014b).

Six case studies to demonstrate the possibility of connecting environmental sensors with BIM and confirming that the process could go in two directions; from real to virtual models and from digital to physical models. (Kensek and Kahn, 2013a).

The case studies referred to the creation of various models using/combining different programs where Dynamo was in most cases used as interlink to Arduino board.

- Interface of Rhino & Grasshoper to Arduino board / microcontroller
- Arduino photoresistor, Dynamo & Revit Simple model - related to shades
- Arduino photoresistor, Dynamo & Revit Building component model - related to rotated shades
- Arduino photoresistor, Dynamo & Revit Building component model and Physical Model related to the photoresistor light level value)
- Revit 3d Model, Dynamo & Arduino Servo Physical Model – (no supporting functions in Dynamo)
- Arduino photoresistor, Revit dll & Revit 3d Model
- Revit 3d Model, Revit dll, Arduino Servo Physical Model

All the case studies demonstrate the possibility of using light sensors to drive parameters in BIM and changing the same parameters in 3d models and enable them to move into a physical model.

As a conclusion from studies it was observed that the interaction time of Dynamo/Revit is slightly slower that Rhino/Grasshopper. The main challenge for Dynamo was speed interaction with the database and all geometry delivered from the Dynamo workflow could be amended or potentially manipulated, or the user can delete geometry in the worst cases in the Revit interface (Kensek and Kahn, 2013b).

This research benefits from above case studies as researchers have been looking into the increasing the 4D modelling capability for better tracking of the project progress. However, not any of the reviewed case studies has this research awareness of the seeking up the methodology to specify the 4D LOD.

3.4.3.4 Analysis of existing concepts LOD and LODt

The level of development (LODt) regulates what the model should be used for and for analysis, regarding expected degree of accuracy. LODt outlines that the details are efficient and informational but only added lines that make one component more fully developed than another (Kensek, 2014c). In general, the level of detail (LOD) purpose is to model an object with the most appropriate geometry and representation agreed with a specific objective of analysis (Ruas, 2004).

Most recently, the collaborative work process applied in the production regarding a conceptual data model to structure information based on requirements was performed in the A507 expressways project in Marseille, France. The practitioners defined differences between the level of detail (LOD) and the level of development (LODt). They presented their conceptual data model in two parts. The first part indicated how an object is linked to the rest of the database through systems and space. Then they introduced how the range of appropriate objects and related information is accomplished to meet required needs (Tolmer *et al*., 2015b).

In Marseille, the project design progression was interpreted by the level of development (LODt). Nonetheless, it has not been commonly approved yet and for that reason, it is a matter for clarification. Companies and institutions which create BIM guides considered different and generally incompatible LODt – sometimes also called Level of Detail – that are specially adjusted to the building project but not to the infrastructure project (AIA, 2013; BIMForum, 2013; BIMProtocol, 2013; Kreider and Messner, 2013a). The only document containing the description for both buildings and infrastructure is the LODt from the BIM Protocol that reflects the entire life cycle of a structure (BSI, 2013a).

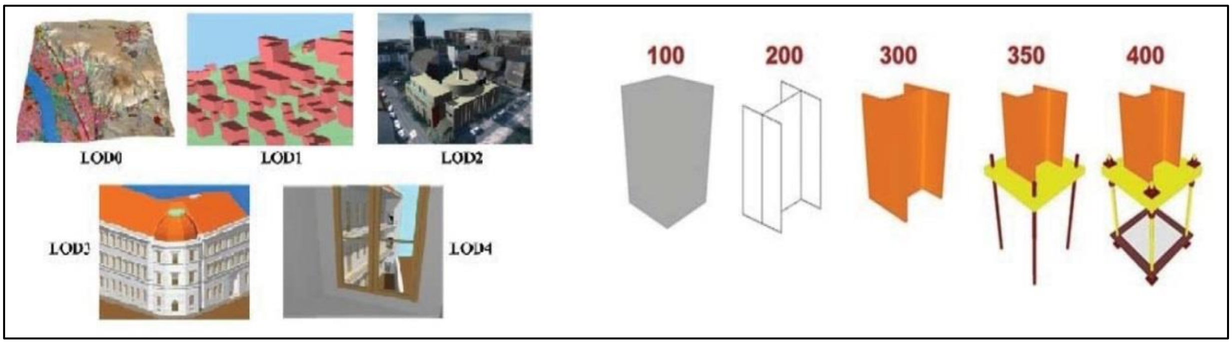

Figure 3.6: Illustration of LOD on the left side and LODt on the right side

(Sources: Groger and Plumer, 2012; BIMForum, 2013)

However, the practitioners considered the LOD established by Groger and Plumer in 2012 and LODt in BIM Forum in 2014 distinguishing their similarities and differences. According to the French team, from a certain viewpoint, the LOD and LODt share a sense of embedding the same sub-concepts such as geometry, complexity or semantic data, which different weightings of this sub-concept. This means that the LODt is divided into two types of levels: level of information and level of detail. Level of information considers quality and semantic parts of an object and level of detail deals with the geometry of the object.

As mentioned before, this proposed approach has not been standardized yet but only suggested for the purpose of the research. In the project, the LOD was used as described in the CityGML standard (Groger *et al.*, 2012). Regarding the LODt, it required only quality and semantic data of an object (Tolmer *et al.*, 2015c).

For the A507 project in Marseille, the work of Biljecki was used as a starting point. Explaining the same sub-concept of the LOD and LODt, Biljecki considered six topics in order to compare them as explicit concepts and implicit concepts. According to him, the LOD has clear and specific geometric complexity, and the appearance and presence of obvious metric of city objects that have to be modelled. The LOD dimension in the sub-concept is not directly expressed. Attribute data that contains the characteristics which depend on the application are not included in the LOD as they are not generic or a detailed object.

The LODt has clear geometric complexity, semantic models and attributes. In the LODt, sub-concept appearance and presence are not clearly defined. The object description of modelling is the subject of its setting and the way it will be used. It is not only connected to the scale of the project although some projects on certain scales can be controlled by the analyses. Regarding this LOD concept, it cannot be used alone in an infrastructure project (Borrmann *et al.*, 2012). A higher abstraction level concept must be presented to integrate the context of the use of the object and the requirements that have to be achieved. It is known that the LODt corresponds exactly to the different stages of a construction project.

Therefore, the LODt object is not always the same for all objects of the specified project phase, but on the contrary they are completely different. The point is that for each new project the use of relative LODt for each object includes partial or complete redefinition. This redefinition would be influenced by the contract, decision or project participants' consideration (Tolmer *et al.*, 2015d).

In the BIM infrastructure project, the structuration of objects and properties, as well as the roles and actors, are identified. Therefore, the exchange of data for specific project requirements is essential. However, the different BIM uses such as plan, design, construction and operation are all parts of the BIM Executing Plan (BEP) and an object can be exposed to numerous BIM uses and therefore includes incompatible sizing and geometries (Kreider and Messner, 2013b). To prevent this confusion, BIM uses should be described in the BEP where each phase clearly defined the information and object required for each BIM use (Tolmer *et al.*, 2015e).

The examination of the case studies and revealing the potential to attempt new systems and processes motivated this study to develop the new technique that would support the protocols for communicating information in 4D BIM simulation.

3.4.3.5 Multi-level of detail

This section focusses on the greatest important subject studded in this research. The cases presented here comprises those that contributed the most for the development of the framework of this hypothesis.

In “Interactive Generation of ‘Multi-Level of Detail’ 4D CAD Simulations”, Heesom considered the role of the graphical level of detail and the temporal level of detail in dynamic construction processes. He stated that existing 4D methods do not take into consideration the changeable productivity elements included in the dynamic construction of building products. Neglecting this issue, 4D simulations are repeatedly run by relying on a single planning interval all the way through the project.

This highlights the lack of methodology in terms of the changeable and temporal level of detail as the particular project inevitably dictates tasks. Furthermore, the planner is in charge of the requirement of the level of detail compulsory for defined operations while helping to semi-automate the connecting and 4D development process (Heesom, 2004c).

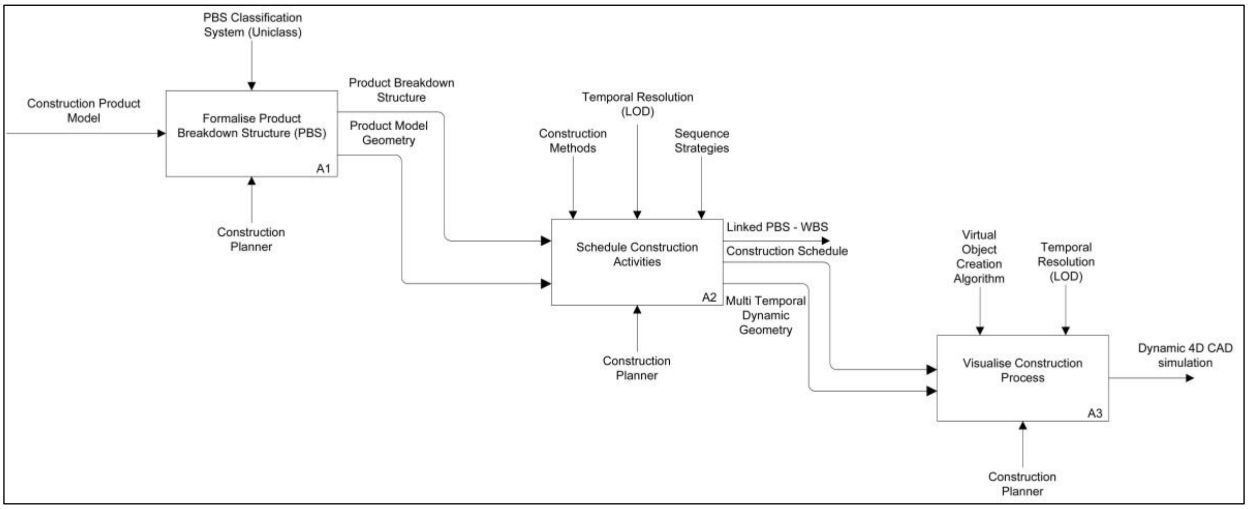

Figure 3.7: Outline system development methodology

(Source: Heesom, 2004)

In his work, Heesom paid attention to the level of detail management considering resolution of the planning prospect and emphasized the resolution effect on the regions developed for the control of the dynamic geometry.

The research study performed by the NeoBuild Innovation Centre (NIC) team on the construction in Luxembourg was focused on the aspects associated to a 4D simulation and issues related to a 4D LOD. The company implemented BIM to experimentally model the building, to deliver truthful information for the construction site monitoring and to include technical data necessary for further facility management. The investigation presented was focused on the pre-construction phase and the construction phase. In the first phase of the experiment, attention was on constructability of technical design varieties and to resolve in advance the classification issues in the early design stage of the project development.

The design work was not completed at the time of developing the 4D simulation, therefore various technical details needed to be defined. However, this did not actually influence the outcomes of this part of the research which was managed at a "low" LOD. The information exchange principle among the project actors was based on the Penn State CIC Research Team's template. This first phase of the experiment clearly emphasized the use of 4D/BIM in pre-construction stage for initial planning.

For this reason, it involved the understanding of the first arrangement of the construction activities over time starting with a rough schedule produced by the architect. This rough schedule provided spatially visualized construction sequences as well as evaluations of the technical constructability, the potential clashes and the other problems in collaborative team meeting periods (Boton *et al*., 2015***b***d).

The architectural design drawings presented from ArchiCAD were used to produce a 3D model. The model was created using SketchUp in LOD 200. The dimensions and the positioning of the structure were accurately modelled but many other 3D components were only estimated. The activity arrangement was recognized inside the 4D Virtual Builder supporting SketchUp. Outcomes and specifics were passed on as a slideshow in MS PowerPoint format. Both the front and the glazed walls were presented in LOD 300. The researchers indicated that this allowed them to analyse the wall construction much better. They pointed out the importance of learning more about the interface between sealing and glazed walls.

At this point the 4D simulation revealed figures to participants about external the staircase and the patio that were scheduled to be built at the time. The construction of the main building was completed and the provisional scaffolding was eliminated. The researchers noticed that this fact apparently emphasized the possibility for the workers to enter the upper floors of the building. They also had access to the roof, for the reason that the two main sites' accesses were "in work" at the same time. This result was achieved by coordinating both the external staircases and the patio tasks (Boton *et al*., 2015***b***e).

The second part of the research was established in parallel with the advancement of the building construction. The main purpose of this part of the experiment was to control and synchronize the project to simulate logistics problems and to manage construction site areas. In this part of the project, many actors participated, apart from the architect, including the project manager and 4D modeller, in order to realize construction parts. Kriphal and Grilo indicated that in this, part of their goals was identified. The 4D model was built based on information inputs such as a 3D architectural model, MEP model and the inclusive task schedule.

The BIM Manager, the MEP expert and the site manager had intentions to plan, control and organize the construction by the numerous professionals, and to visualize and evaluate conflicts and clashes in models before construction works started (Kriphal and Grilo, 2012b).

The team developed four separate models. Autodesk Revit was used to develop the architectural model (MI) at LOD 350. In this model, the front wall was demonstrated at LOD 400. Parallel with this the conception of the MEP model (M2) was built at LOD 200 by the use of Plancal Nova. The team upgraded the MEP model to LOD 300 by adding constraints with Revit MEP. Furthermore, the third model (M3) was built with Revit at LOD 100 as the logistic model based on the architectural model having general logistics components.

The instruction schedule planned by the architect was detailed in MS Project. The files from three models were imported into Navisworks and the 4D model was created (M4) (Boton *et al*., 2015***b***f).

The NeoBuild team indicated that the project manager at this stage used a 4D model for clash detection. Logistics management used a 4D model to indicate restricted areas, garbage collection, locating of cranes and scaffolding movements. The team indicated the importance of the 4D model in the coordination of actors especially in complex work regarding the wooden wall construction sequence. In addition, they pointed out the time spent on the model work in both pre-construction phase and construction phase during the case study, of work completed in the pre-construction phase, the modelling of architecture components was the most time-consuming as many errors occurred due to BIM software being used wrongly.

The creation of logistic model (M3) did not take much time and effort as it was built at LOD 100. In the construction part of the case study, the use of the models previously created for different purposes that were outlined in the BIM workflow approach benefited participants. Only the logistic model was generated by a 4D modeller in the construction phase of the study. In the second part of the research to create the 4D model more time was needed as the number of components and details were higher. However, the team noticed that despite the higher number of elements and detail needing to be managed, the results were more accurate and less time was spent on work than in the pre-construction phase.

The BIM workflow and the good coordination during BIM processes where other models were created assisted a 4D modeller to reuse them for the 4D simulation (Boton *et al.*, 2015***b***g).

3.4.3.6 Graphical level of detail

Boton's team indicated that the Level of Development used in the pre-construction stage was from LOD 200 to LOD 300. In the construction phase, LOD was from LOD 100 to LOD 400. With their research they confirmed that the LOD required for the construction phase is higher than the LOD needed in the pre-construction phase (Kriphal and Grilo, 2012c).

They concluded that a single LOD is not adequate especially during the construction phase. They realized that different levels of development were needed for visualization and coordination depending on the 4D model purpose and the specific construction problems that occurred during construction and modelling processes. The researchers highlighted that the choice of LOD depended on the usage of the simulation as this was not even throughout the building progress phases and also specific to the project and productive coordination.

Moreover, they indicated the need for additional 4D details which were found to have specific issues during the investigation, as they were not defined precisely enough which led to the conclusion mentioned (Boton *et al.*, 2015***b***h).

3.4.3.7 Temporal level of detail

In the pre-construction phase, the rough schedule was available therefore the 4D modeller based his work on estimated arrangements of construction processes. As the construction processes in a 4D model in the first part of the case study were not based on the dates or work breakdown structure, the correspondence between the graphical LOD and the temporal LOD was very hard to manage. For this reason, the temporal LOD was developed from the 3D model LOD. Although the detailed planning was presented from the commencement of the construction phase, the LOD was at very low level delivering the main stages of the construction process.

The project element analyses were not at the same LOD as the 3D model components. Even though the site manager was provided with the detailed schedule, this document did not cover the whole construction process. The whole thing initiated extra work for a 4D modeller outlining the sequence signifying detailed activities with the aim to make them correspond to 3D model elements.

The team pointed out that the extensive amount of work in the Luxembourg project was initiated mostly in areas of procedures for managing temporal LOD requirements. It was essential to pass on selection sets' classification from a 3D model, to categorize the activities parallel to the selection sets and to approve the classification with the site and project managers. Furthermore, the improvement of the new schedules was necessary when linking construction activities to 3D building components (Boton *et al.*, 2015***b***i).

Yet again looking into the issues around the temporal level of detail, this study comes to the conclusion that 4D model compensates for the lack of dynamic elements particularly because of the neglect of the temporal level of detail at the early stages of the design planning. Instead of dynamic work and dynamic 4D simulation, a lot of repetitions need to be done, producing workload and frustration. According to Han and Golpavar–Fard (2015), nonappearance of the appropriate level of detail in current planning practises cause inability to track the progress on individual element basses.

In the course of this research, an extensive literature review clearly establishes a link between the level of detail, planning practices and sufficient information flow. Therefore, the most important findings presented in this thesis are justification for creating innovation to assist the 4D models in construction project complexity.

3.4.3.8 Communication between the 4D model and construction site during construction phase

The research team paid attention to how the communication and exchange of information was made between the 4D model and construction site. They benefited from the 4D model in the sense of being able to deal with the construction problems which were predicted before they appeared on the construction site. However, some construction issues could not be anticipated, therefore when these problems occurred, the feedback would be used in a 4D simulation to evaluate alternatives. Having this possibility, the team was able to choose the best solution and to update the model (Boton *et al*., 2015***b***j).

On the other hand, it is obvious that a limited number of researches worked on the 4D LOD issues. The temporal level of detail is usually taken from the 3D model LOD, which does not show the detailed activates and additional work is needed for the temporal level of detail to correspond to 3D models elements. Having no temporal LOD guiding principle requirements is a drawback in the whole AEC industry. This research and the proposed approach for the standardized method of specifying the 4D LOD would bring a valuable contribution to the industry.

3.5 Summary

The literature presents many papers on Building Information Modelling and its importance in the construction industry. Nowadays there are sources that provide the implementation of BIM data in practice. BIM protocols and principles are guidelines to lead the project team members in how to implement BIM and develop an execution plan for BIM in practice. However, the technology is still recognized as an evolving technology as the project planning is crucial for using BIM in a project in order to succeed in the BIM usage.

Although 4D modelling has been a research area for more than two decades, even before the introduction of BIM, 4D technology had advanced for the reason of the BIM three-dimensional models. Many research projects highlighted the importance of effective planning being one of the most important aspects of 4D modelling. The level of detail included in BIM when planning a BIM project dictates the level of the model. These levels of detail used for 3D modelling have to fit with the 4D simulation construction activity schedules. As the project participants have to plan the project, they also need to plan the process of exchanging different information during the construction project.

The 4D model is known to improve the construction project by providing better communication which is needed on collaboration projects because the numerous design stages of the architectural process involve the collaborative of many disciplines. This research focuses on the importance of 4D LOD on communication in the construction project. The LOD explanation which is used in the industry to classify the totality and the precision of the model does not include specific construction procedures. The static image of a 4D model does not fully represent the dynamic construction project.

Virtual prototypes with implanted assembly information should symbolize constructability to support workers in the field. When keeping a record using the 4D visualization of the real world, the user can review changes in the correspondence to the real-world setting. The visualization of 4D data maintains the context of the changing environment throughout the project and tracks changes over time. Nevertheless, variations of a complex nature are challenging to understand and in addition, these visualizations lack the context of the real world. Therefore, the research concentrated on the idea of multi-level of detail.

This approach would achieve visual complexity and visualization adjustment providing a more realistic view of the environment.

Furthermore, planning is always seen as the main aspect for 4D technology. As-planned and as-built is the method to allow workers to compare the project development from an up-to-date point with the planned one. With this methodology the visualization may suffer from the clutter if many parts are different. As a result, this technique may fail to create clear visualizations for numerous changes, such as tasks for progress or completion analysis. The literature introduces many case studies praising 4D technology for increasing communication through visualization, decreasing the networking and delivering better budget control as well as improving safety management on site.

The literature draws attention to technology limitations such as having no clear evaluation and the duration of activities in the project. The lack of construction plan information as the construction activities could not be all visually presented is due to the absence of more dynamic 4D simulations in order to achieve more reliable outcomes. Although the importance of the graphical and temporal level of detail in 4D modelling is recognized by practitioners, the available literature includes only a few case studies on 4D LOD.

Chapter 4: Methodology and Proposed Approach

4.1 Introduction

The following chapter offers an extensive justification for a methodological approach for this research. This is an additional attempt to present in detail the noticeable issues which are found in the literature review carried out. In Chapter 2 and Chapter 3, diverse approaches in different case studies and methods to 4D technologies were introduced, indicating critical issues for improvement. Nevertheless, it is not always clear as to how to use and integrate them when aiming a particular type of study and how to assess the data. This chapter outlines the approach and methods applied to this research.

Firstly, the purpose of this research is to increase the collected knowledge through the means of recognizing, considering and generating results to an unsolved problem. According to this research analysis the matter of improving the 4D dynamics ought to be viewed in construction planning, improvement of collective responsibilities as well as the level of detail in construction processes.

This research found, established in the literature, all the construction planners and participants showing interest in implementing 4D technologies lack of awareness in process as well as missing collective responsibilities in the construction policy regulation; proving the current inadequacy in the level of information

4D planning should be enhancing communication amongst various parties involved in construction through adopting visualization for business needs, reduction in rework by having automated system of minimizing conflicts and provide better budget control as well as improving safety management on site.

The aim of the study is to investigate a methodology directed to the development of a concrete framework and recommended approach for the execution of new functionality software for an improved dynamic 4D model. As the level of detail stages, the records the model must include according to its use at the numerous phases of a project lifecycle the multi-level of detail is the strategy to be framed in the anticipated method. Emphasis shall be focused on possible improvement on 4D software of speed interaction with database and better accessibility of modifying workflows in Revit.

The temporal LOD is the time related component which represents various stages in 3D model construction operation. The whole construction process is quite dynamic and sometimes unpredictable, so could change the operation at any time while other operations require significant time so any change could take effect in the 3D model.

It is apparent that 4D simulation does not cover varying productivity factors used in dynamic construction processes and that causes common usage of single planning intervals for the entire project duration with no automated adjustment of temporal LOD. Automated concept was meant to provide a more dynamic and realistic method for space planning in the construction industry.

4.2 Research Methodology

In the following sections, the research justifies the proposed approach and research methodology, giving explanations for the chosen research design, research strategies as well as research data collection and data analyses and techniques.

4.2.1 Research Design

The purpose of a research design is to make sure that the evidence gained supports effectively addressed the research problem rationally and as clearly as possible. It refers to the general strategy chosen to incorporate the different components of the study. The most suitable approach to be applied for the research depends on research aim and objectives. The types of research design are (Cuthill, 2002; Farooq, 2013):

- Exploratory Research Design – when there are few or no earlier studies to refer to
- Descriptive Research Design – describing a particular situation or phenomena under the study
- Diagnostic Research Design - describing factors problematic for the particular situation
- Experimental Research Design – maintaining the control overall the facts that can affect the experiment

An exploratory design was conducted as the study aims to create a framework for developing 4D LOD on construction project and there have been few information in the literature on the subject. The exploratory design helps in establishing an understanding of how best to proceed in study and what methodology should be applied for the efficiency in collecting information about the research problem.

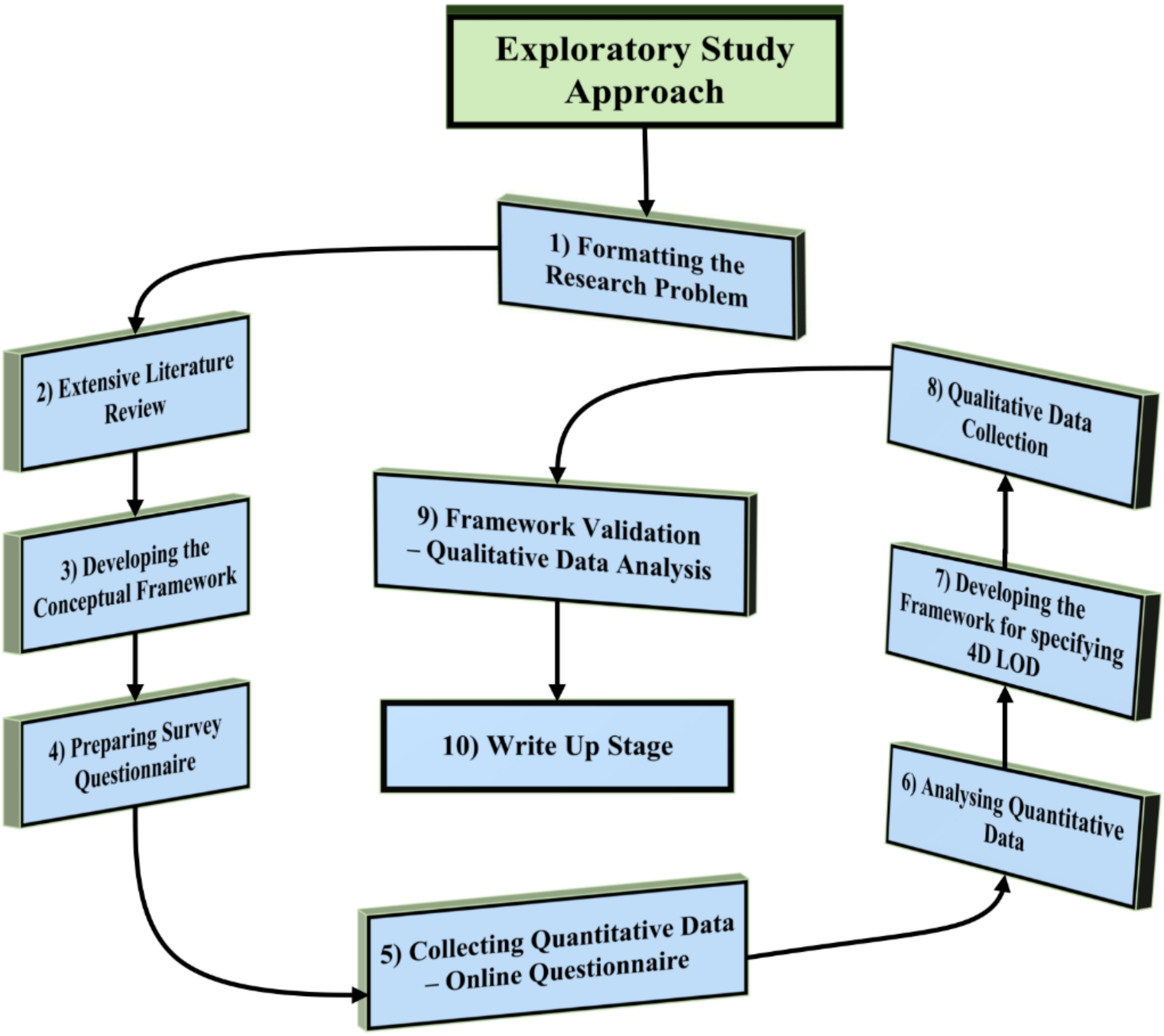

Figure 4.1: Exploratory Research Design Diagram

The research highlights this study concern for improving the 4D performance, but in the few earlier studies on this subject, it was not given the answer on the question: how this could be enriched. The plan of how this study would go about answering the research question was given in Figure 4.1. The research design diagram grasps all the parts and phases of this research assignment and put them together in a resendable progression.

The proposed research design starts with a formatted research question and identify the information from literature, then specify sources from which data will be collected, and the types of data needed for the research.

The quantitative research method of the study included distributed online questionnaires in search of quantified data with statistical analysis.

The qualitative data collection in this research was done on a small number of participants to seek for the closing insights on the topic by the industry actors (Shukla, 2015).

4.2.2 Research Strategies

The research strategy used in this study was chosen regarding the way that the research objectives can be answered. The decision for the adopted research strategies was made on the acknowledged purpose of the study and the type and accessibility of the information required (Naoum, 1998).

The study initiated the quantitative research strategy and qualitative research strategy to accomplish the study objectives.

The quantitative research measured with numbers and analysed with statistical procedures helps to conclude whether the theory holds truth. (Creswell, 1994). One of the study objectives is to explore issues around 4D use and issues of Level of Detail within 4D technology. This objective was fulfilled by gathering opinions from the industry actors in the bigger number using the quantitative research strategy.

The study holds the theory that insufficient 4D Level of Detail is used in 4D simulation, and thus, this is a drawback for this technology. Quantitative data gathered in this research shows that most responders agree if 4D model shows more details, it could improve the technology. The high percentage of the responders who participated in this study could have been achieved only by using quantitative research strategy. For this research and its overall accomplishment, it was crucial to gather the opinions of those who have experiences with work on 4D simulation.

As indicated in section 4.2.1, this is exploratory research mainly because there is a gap in the literature regarding the topic. The exploratory research design also includes qualitative data collection. After undertaking the analyses of hard, measurable data qualitative research was executed for the gaining opinions and perceptions from industry experts. In this study, six online interviews were conducted (one on one), and the sufficient information was collected.

4.2.3 Research (Data Collection) Techniques

This part, presents a clarification of the proposed approach of data collection. The research essential elements are the aim and the objectives as they direct the appropriate research methodology (Saunders, *et al.*, 2012). The study includes collecting data from: the literature review, survey analyses of online questionnaire, and analyses of online interviews.

4.2.3.1 Literature review

The importance of the literature review has been seen in providing an insight in the current state of the knowledge (Saunders and Lewis, 2011). The identified gaps in the literature on the given subject specified in this research are evidence that research is original and relevant contribution to knowledge. In this study the literate review helped the recognition of the initial steps for the gist for the creation of the conceptual framework.

In the Mind Map (Figure 4.2), which was based and created on the findings in the available literature, the focus is made on the centre of Dynamic 4D model (D4DM) where that End-Use is the last operation to be done after all works is complete in the centre of D4DM and can update models for any requests or decisions and do continues repetitions. The construction planer should decompose a single component into sub elements according to areas and related activity into sub activities. This technic proposed by Akbas and Fischer (2002) is included in the diagram.

The study agrees with the statement: that these areas can be created at different levels of detail to contribute in a more comprehensive view of the schedule (Fischer *et al.,* 2000). Many parts, including the shape of the construction zone, impact the efficiency level used during the progress of the dynamic phase of the geometry axes (Akbas *et al.,* 2001).

Reverse engineering was looked at in detail in this study. Reverse engineering can be categorized as a three-stage method: decompose, evolve and recompose. As the study is concentrated on improving dynamic of 4D modelling as well as enhancing the collaboration among the practitioners, reverse engineering could be the key factor for recovering information from existing software and systems. For making the design and project operations as good as possible the human-computer interaction is needed. The importance of the design is equally important as engineering characterises depends on both visual qualities and quantitative analysis, to function.

The IFC-format offers the possibility to compare as-built elements from model images with as-planned models providing the percentage of completed construction tasks.

A 4D simulation contains a link between both the 3D model's objects (graphical LOD) on one side and the construction activities' time schedule (temporal LOD) on the other. They are both usually in part of asynchronous process. It is important that a 4D model's LOD specification must manage graphical LOD and temporal LOD information. The work in progress in the centre allows the planer to monitor different stages of the model at different level of detail where various levels of development were defined from LOD 100 to LOD 500 produced at various construction times during different construction task.

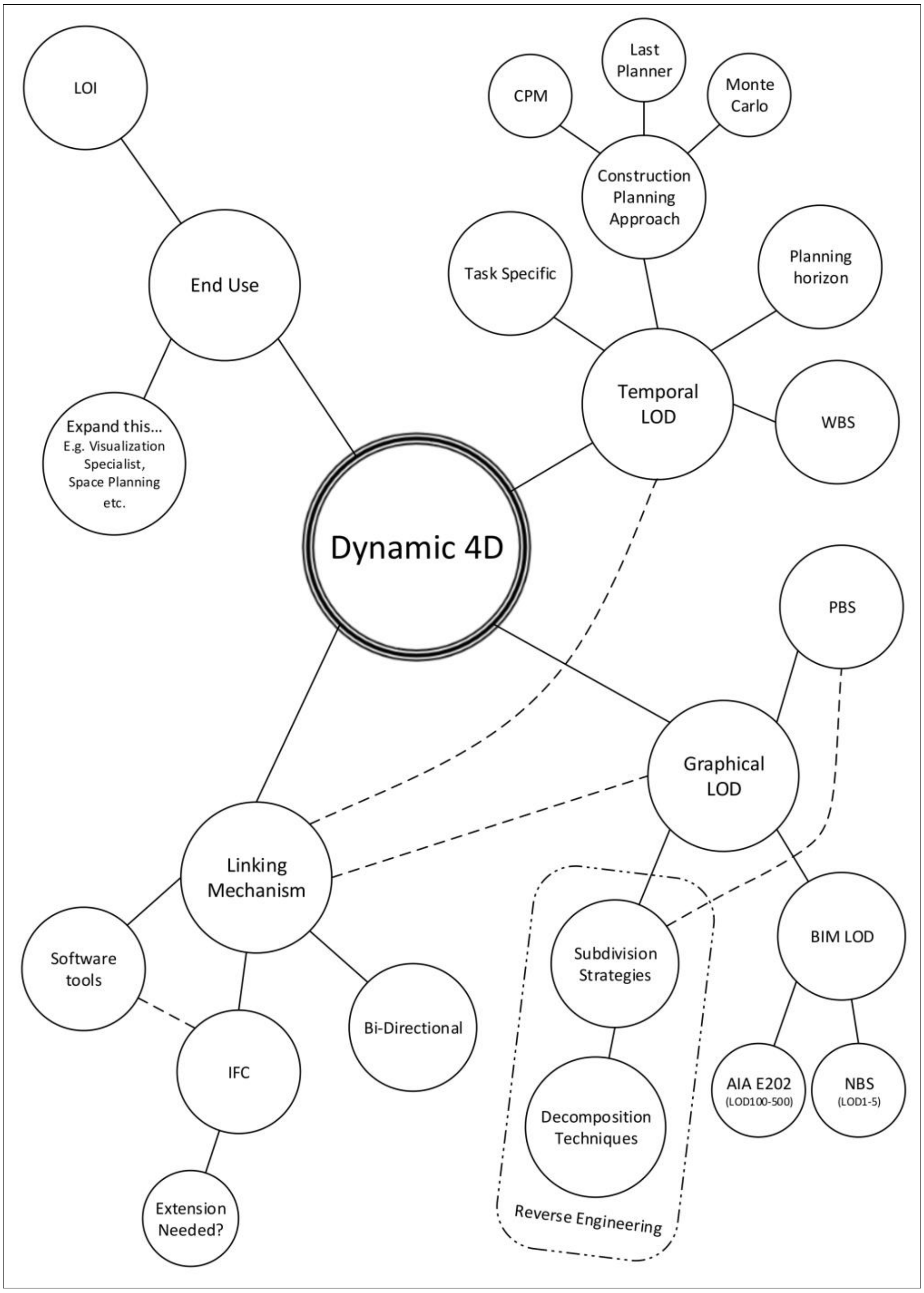

Figure 4.2: Diagram of Dynamic 4D Model (Mind Map)

For efficiency, it is crucial that the shielding tasks for the execution only start when previous tasks have been completed and all the assets are available. Prepared tasks as such are identified as quality assignments which allow the managers to reduce equally the cost by improving efficiency and decrease the time of execution by eliminating potential uncertainty. In cases where resource consumption is not reduced due to interruptions of commencing the tasks as an effect of shielding, the managers are likely to build up buffer frameworks of quality assignments of the critical path, under which full resources can be distributed.

This method is known as the “last planner” as formation of quality assignments is the last phase in the project planning process. The last planner concept is a bottom-up reengineering method concentrating on the production development rather than the system. The last planner needs the automated concept of reengineering. The understanding of complex models could be aided by the technique of model decomposition that subdivides models into smaller significant sub-model to order its conception. The planning prospect is usually one week and the decision-making development is given down to the level of first line management.

Levels of accuracy that are possible in the budget are usually seen through the appraisals of product breakdown structures (PBS) used for initial-stage budgetary planning and the work breakdown structure (WBS) used throughout the scheduling and implementation phases of the project (Winch, 2010g).

The above mind map and its explanation is the brother aspect providing the better image of the current industry 4D technology components. The 4D important components are linked in a specific way to deliver better focus on needed elements for the next step in this research. The above mind map explanation was the starting point in the development of the conceptual framework.

4.2.3.2 Conceptual Framework Methodology

The evaluation carried out in previous chapters revealed numerous limitations and possible opportunities in established construction planning techniques and tools. Taking in consideration the reconized limitations with existing methods to 4D technologies led to the development of a new framework for more dynamic 4D modelling.

The anticpated framework attempts to focus on the key issues identified in the literature review and key elements of 4D modeling shown in the Mind Map Figure 4.2. This conceptual framework is set to address problems acknowledged with current construction planning practice and the drawbacks and future capabilities of 4D methodologies through the application of new technological solutions, in the direction to strong and innovative appraoch of construction plan creation.

It is anticpated that the application of this framework would improve current planning practices by allowing appropriate, visual planning through in-built communication within a building information model. Furthermore, more dynamic 4D model would promote and enable more collaborative and coordinated construciton planning.

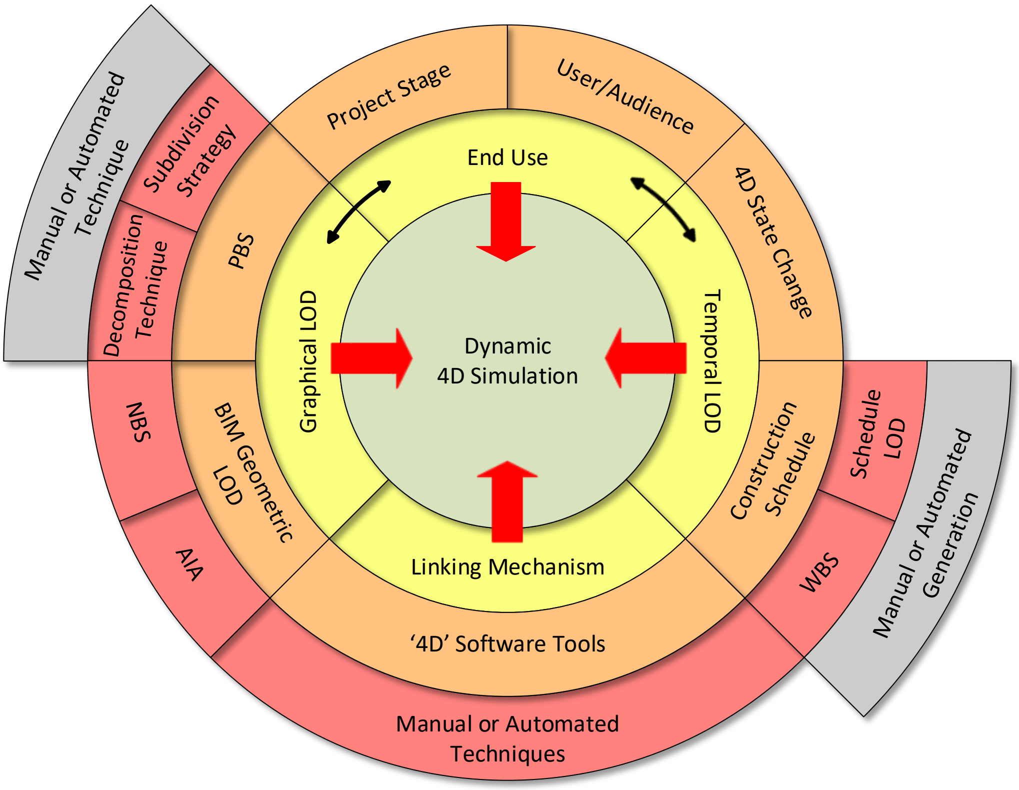

Figure 4.3: Conceptual Framework for dynamic 4D simulations

(Source: Butkovic and Heesom, 2017)

The proposed framework emphasises necessity for planning, controlling and coordinating construction phases using visualized analysis of conflicts and clashes in models even before construction works. The importance of LOD is to specify all information that the model needs to have included at every stage of the project duration. It is apparent that in 4D models, LOD specification should manage graphical levels of detail and the temporal level of information in order to deliver realistic and more reliable 4D simulations (Tolmer *et al.*, 2015f).

As the construction project planning concentres greatly on time and cost management planning this is a continuous task. The WBS method delivers an extended way to calculate, outline, measure and control the elements of a given work scope. This is the reason why the PBS and WBS must be included in the framework as the PBS is part of preliminary project phase financial planning and the WBS is part of the development of project execution and the scheduling during the course of the project.

The space planning in construction has two leading features that are co-dependent, but they need relatively different approaches. One is a scheduling problem, concentrated on the planning of task execution spaces. Second is the site layout problem focuses on the settling for temporary services of various kinds. (Winch, 2010h) Reducing task duration and providing execution of the tasks as efficiently as possible in a collaborative context is important for regaining the control by project management who carry whole responsibilities of managements.

The capability to decompose building products in a 3D model is fundamental in the execution of accurate multiple level of detail. The development of the geometry reflecting the development of a building product is essential to be presented and to be created on the temporal resolution of a construction task. (Heesom, 2004d) The technique of model decomposition that subdivides models into smaller significant sub-models is a great asset for understanding the complex models.

It is apparent 4D simulation does not cover varying productivity factors used in the dynamic construction process and that causes common usage of single planning intervals for the entire project's duration with no automated adjustment of the temporal LOD. The automated concept was meant to provide a more dynamic and realistic method for space planning in the construction industry (Heesom, 2004e).

The human computer interaction is seen in designer's need for qualities characteristics demand evaluation which has significances for optimization. Computer graphics and applications involve visual designs of images, animation and 3D virtual reality and products. In building design, the engineering characteristics are just as important as the aspects of appearance. The function deepens on visual qualities and quantitative analysis.

When it comes to choice of software suitable for framework it would be necessary to use more software applications in order to integrate design and planning information. Autodesk Navisworks could be considered as one of the good visualization software as supports various numbers of BIM formats and permits the importation of schedules from a variety of sources. Navisworks supports manual and automatic linking to import schedule data from variety of schedule applications. The software allows the user to join the item in the model with the tasks and simulate the schedule.

4.2.3.3 Online Questionnaire

The literature review and gaps detected in literature initiated many questions and the need for the quantitative research method was raised.

The specific issue of the LOD within a 4D simulation still requires attention. Primary research has been undertaken to understand issues surrounding the implementation of 4D within the construction industry around the world including the UK, Australia, the US and Iraq (Gledson and Greenwood, 2016; Kim *et al*., 2016; Hamada *et al*., 2017; Wong *et al*., 2011). However, these efforts have focused on the implementation of 4D as it currently stands and did not specifically focus on the issue of the requirements of Level of Detail (LOD_{4d}) of the 4D simulation.

Consequently, this study adopted the approach to solicit the opinions of expert users from the industry in order to develop deeper knowledge of the requirements of more dynamic 4D simulations. From this a framework is proposed to provide an approach to specify the LOD during the planning process and subsequently allow multi LOD simulations to be developed within the 4D session.

This quantitative data collection was gathered by the use of the online survey questionnaire. With the open-ended formats, these types of questionnaires are practical cost-efficient and give prompt results. The online questionnaire allowed the information to be gathered from a large audience and internationally. The research had looked for currently the most appropriate way to perform the survey. The internet is widely used and offers possibility of swift communication and opportunity to question experts in the chosen field in order to acquire their opinion.

An online questionnaire was developed with a survey period between Q3 of 2017 and Q2 of 2018. The target sample population of the study was those who actively engaged in using 4D simulations on a range of construction projects across a section of companies identified from industry case studies. A total of 101 questionnaires were issued with 82 responses being received. Of these responses a total of 61 fully completed questionnaires were received (response rate of 60%) and treated as valid for the purposes of analysis.

Demographic Information: The initial part of the questionnaire sought to gain a level of demographic information on the responder, the type and sector of company worked for and the nominal size of the projects the company engaged with. The purpose of this was to identify the role of the participant and to ascertain if any of the results around the use of 4D, and particularly the issue of LOD, was affected by the nature of the company and the type of construction work engaged in. This also included an element of the survey that investigated the role of BIM in the company and particularly the usage of technology to support the BIM process. This focused on the 4D software tools and the project planning tools implemented to provide a backdrop of technology usage.

Usage of 4D: The second section of the questionnaire elicited deeper information on the usage of 4D both from a technological standpoint of who took responsibility for the creation and also how the 4D simulations were used once generated. Building on this it went on to determine what graphical and temporal level of detail (LOD_{ti}) was used at the moment for each of the use cases of the 4D simulation.

Construction Tasks: The final section of the questionnaire presented the responder with a range of typical construction tasks and asked them to identify to what LOD_{ti} they believed would be most appropriate for that task(s). This section aimed to derive whether there was a need to obtain a range of LOD throughout the lifecycle of a 4D simulation depending on the work package being undertaken at any discrete point. Descriptive statistics were used to develop an overall picture of the use of 4D and the issues surrounding the Level of Detail, including the potential of the 4D simulation to show the construction process at a range of graphical and temporal level of detail.

This would then inform and support the development of a framework for the creation of 4D simulations that contain multiple LOD, which can be implemented for the full range of the construction process.

4.2.3.4 Online Interviews

The online interviews were conducted in the validation stage of this study. The choice for the live text chat was seen in the need for the qualitative research method by selecting 6 industry practitioners from 4 different countries. The qualitative type of the research was appropriate for framework validation as attempt was to gain impressions, opinions and views from the responders. The sampling size was chosen as the framework validation needed to be discussed in-depth.

In this study, the focus was pointed on the strategic methods looking for the perceptions that are relevant to the primary goal of the research. In this research, after the formatting questions that needed the answering to extract best possible value from the information available the most valuable data sources, are the industry participants who work on 4D technology on daily bases.

For collecting the qualitative data in the live text chat, this research applies the same reasons indicated in the justification for collecting quantitative data over the internet survey questionnaire. Benefits of the internet are in prompt communication, and in this research, this benefit was seen in instant communication with participants who were in 4 different countries.

4.2.3.5. Data Analysis and Technique

Data analysis of research is a critical stage as it helps examines the gathered information in achieving a suitable conclusion. When the deadline for the questionnaire completion passed the study moved to check whether the questionnaires' procedure was accordingly followed. Questionnaires which were not completed had been omitted before the data analyses started.

The received information was transformed into metrics, facts and figures which provided advantages that benefit the improvement (Durcevic, 2019).

This study has chosen the descriptive statistical analyses where it was worked on:

- Mean – average number of a set of values
- Mode – indicating the most common values among a set of values
- Percentage – used to specify in the percentages how a group of responders within the data shares the same opinion in relations with the group of others with different answer
- Frequency – the rate of the same answer occurrence
- Range – the difference between the most given answer in the survey and the less common answer in the survey

The percentage use was needed to specify the practitioners exhibiting a certain performance while working on 4D simulation. Frequency of the repeated answers is important in this research as it would justify even further the reason for the research. Range of the differences also plays a significant role in this study to indicate the difference between the largest and smallest values (Bhatia, 2018a).

Apart from descriptive data analysis for the quantitative data, the inferential analysis in the form of correlation was performed in a few questions of the study analyses. For example, the correlation was used by crossing the answers between two different questions, such as the occupation role of the responders and the way of the use of 4D simulation in the project.

Or else correlation was used for questions how 4D BIM was used in the project in comparison with the question should the single element in 3D model be subdivided into smaller sub-elements of the models to show more detail during the 4D simulation. This was needed in this research to provide the relationship between various variables to generalize results and make estimates.

In this research it has been chosen the use of Statistical Package for Social Sciences (SPSS) to analyse the quantitative data of the study. The capability of SPSS is really astonishing. The package enables obtaining statistics ranging from simple descriptive numbers to complex analysis multivariate matrices. The techniques incorporated in the package are analyses, amends and production of a specific pattern between different data variables. There is also possibility for a graphical demonstration of the results (Thomes, 2018).

In this research preparing qualitative data analyses was done by identifying patterns and connections. After implemented online interviews the study was looking for the most common responses to questions. The data gathered by the interviews was acknowledged in a way to answer research question (Bhatia, 2018b)

The research executed 6 different interviews with industry experts from 4 different countries. Each responder was asked 10 questions and this was provided as documented information in the arrangement of media text and this text was suitable for content analyses in **Appendix G: Framework Validation Interviews**.

4.3 Summary

This chapter presented an overall research methodology clarifying the phases for data collection, creation of conceptual framework, and data analyses techniques utilised in this research. Precise reference to the initiates within each phase given and particular tasks executed within each phase have been look over against its validity and the significance to the research.

This chapter facilitated this project to advance with a clear view to deal with the problems emphasised during the investigation. Moreover, this chapter offers a base to course of data collection methods in order to analyse and form grounds for the proceedings.

Furthermore, the research has identified communication problems. There is an absence of good communication mechanisms, weak executive arrangements of project teams, lack of constant standards for construction information and insufficiency of support for progressive communication technologies. The key for achieving better communication starts with project planning and creating dynamic model which captures the changing requirements of construction sites.

With the intention of move the research process forward the possible problems for the study had been indicated and the theoretical framework was introduced in this chapter. The critical parts of the conceptual framework are the graphical level of detail and various levels of temporal details. Both graphical and temporal levels of details are influenced by numerous factors crucial for construction project.

At the current stage of this research the questionnaire has been developed for data collection in order to propose the framework that can benefit the industry. This is explorative research where the suggested framework is built around the technologies that are already in use in the construction industry as shown in the literature review of this study. By carrying out user evaluation the collected information reveals the potential usefulness of the proposed tool. As the developed framework includes four specific areas such as graphical LOD, temporal LOD, linking mechanism and end of use.

These areas are divided into subsections in order to enhance construction planning and 4D attributes. The survey form was developed to examine if the anticipated tool had addressed each of these issues. The chapter also refers to the different technics for the data collection suitable for the study.

Based on defined methodology the following chapter presents detailed quantitative data analyses.

Chapter 5: Survey Analyses

5.1 Introduction

At the initial stage of the survey, the pilot survey was conducted; attention was paid to issues of validity and reliability of the questionnaire preparation. It was ensured that feedback given by five respondents for the pilot survey were assessed and identified omissions in wording of the correction on some questions in **Appendix E: Contract Review**.

The questionnaires were sent out by the email using a link to the online survey is followed by two follow-up reminders. The survey period was accounted and dated as up to the end of January for seven weeks starting from the first latest December through with an idea of extending survey for additional four weeks until the end of February. All questionnaires were posted to one hundred participants on the same day in **Appendix E: Responses**.

By the end of January, 68 responses to questionnaires were received as shown in the Table 5.1 By the end of week 12, the total of 82 responses were received. Responders tended to respond to questionnaires mostly during the last week of the questionnaire period or immediately after being engaged by follow-up emails. Upon accessing the survey URL https://www.surveymonkey.co.uk/r/bogdanbutkovic, responders proceeded to an introduction web-page followed by the first page of the questionnaire.

Table 5.1: Questionnaire administration

Date	Survey duration (Week)	Number of responses to questionnaires		Follow-up (reminders)
		Completion	Incompletion	
11th December 2017	1	3	5	
	2	2	1	
	3	1	0	
1st January 2018	4	15	2	3rd January
	5	14	2	
	6	6	0	18th January
	7	4	3	
	8	6	4	
5th February 2018	9	2	1	
	10	4	0	12nd February
	11	3	1	
	12	1	2	
	Sub-total	**61**	**21**	
	Total	**82**		

The first three weeks of the survey revealed that a number of targeted respondents were out of the office for their Christmas and New Year holidays. Hence, to achieve a satisfactory response rate the response time was extended by four weeks for the completion of the questionnaire.

The first and second follow-up of reminders were conducted to engage those returning from the holiday and who agreed to complete the questionnaire during the follow-up rounds. This accounted for a total of 30 questionnaires being received by the end of week four. By the end of the questionnaire period (12th week), a total of 61 completed questionnaires (response rate of 50%) had been received. At the end of the week eight, the total response was 68 among which 51 were fully completed (valid) while 17 were excluded due to incompletely answered questionnaire.

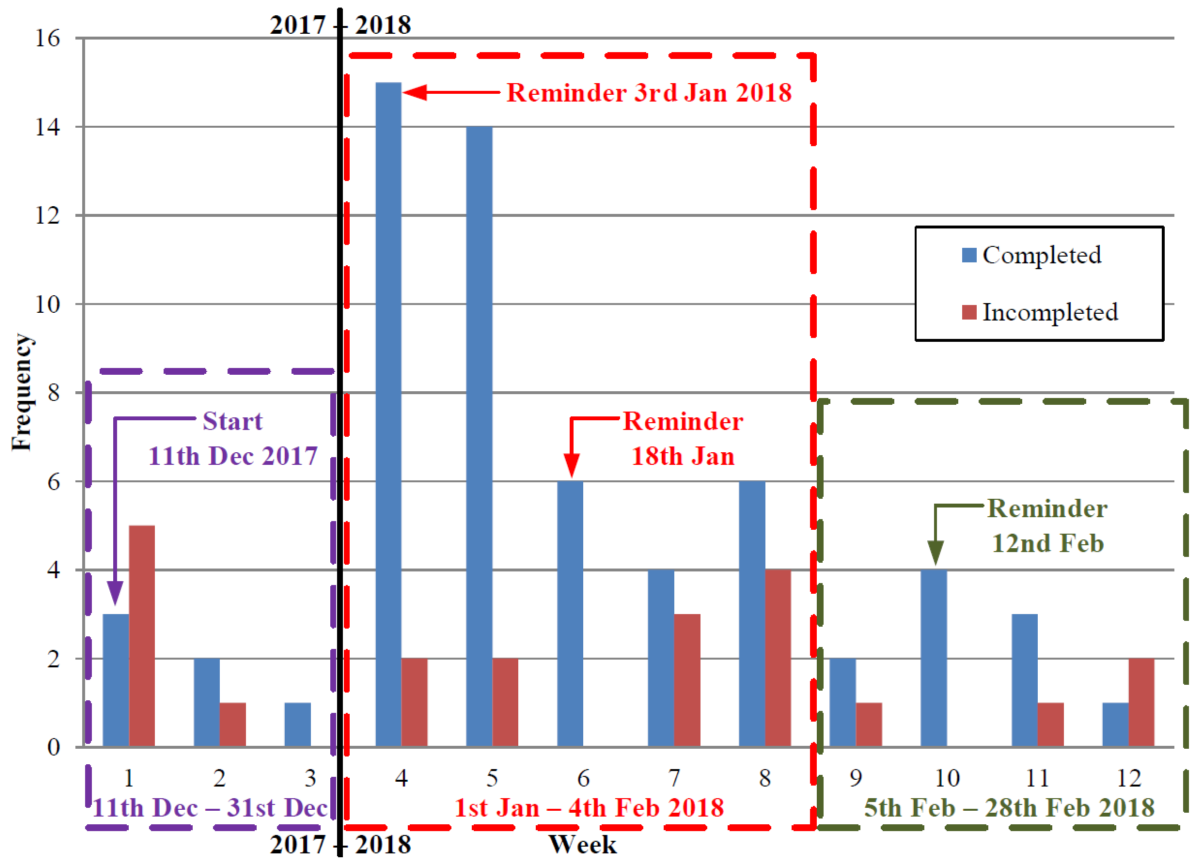

Figure 5.1: Questionnaire administration in a bar

5.1.1 Survey Analyses

As the survey is the state of sending one hundred questionnaires to the selected companies in the UK and the outside through international companies of which 61 were returned fully answered (valid questionnaires). To obtain a global description of the valid survey, the sample started with related tables and charts to questions.

The survey analysis was conducted in descriptive and correlation research methods.

Unlike in the case of the descriptive research where the focus was on collecting descriptive data, in correlational research attempt was made to identify association that exist between variables. An effort was made to understand the nature of the relationship as well and how some of the responses have variable influences.

5.1.1.1 Demographic Information

Table 5.2: Occupation role (Q1a)

Occupation role		Q1a: (Occupation role)			
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Execution role: General	1	1.6	1.6	1.6
	Management role: CEO	5	8.2	8.2	9.8
	Project Manager	6	9.8	9.8	19.7
	Building Surveyor	1	1.6	1.6	21.3
	Main Contractor / Suppliers	1	1.6	1.6	23.0
	Software Programmer	3	4.9	4.9	27.9
	Planner	3	4.9	4.9	32.8
	Architect / Lead designer	6	9.8	9.8	42.6
	Information Manager	4	6.6	6.6	49.2
	BIM Manager / BIM Co-ordinator	22	36.1	36.1	85.2
	Cost consultant / quantity surveyor	1	1.6	1.6	86.9
	Civil Engineer	1	1.6	1.6	88.5
	Other	7	11.5	11.5	100.0
	Total	**61**	**100.0**	**100.0**	

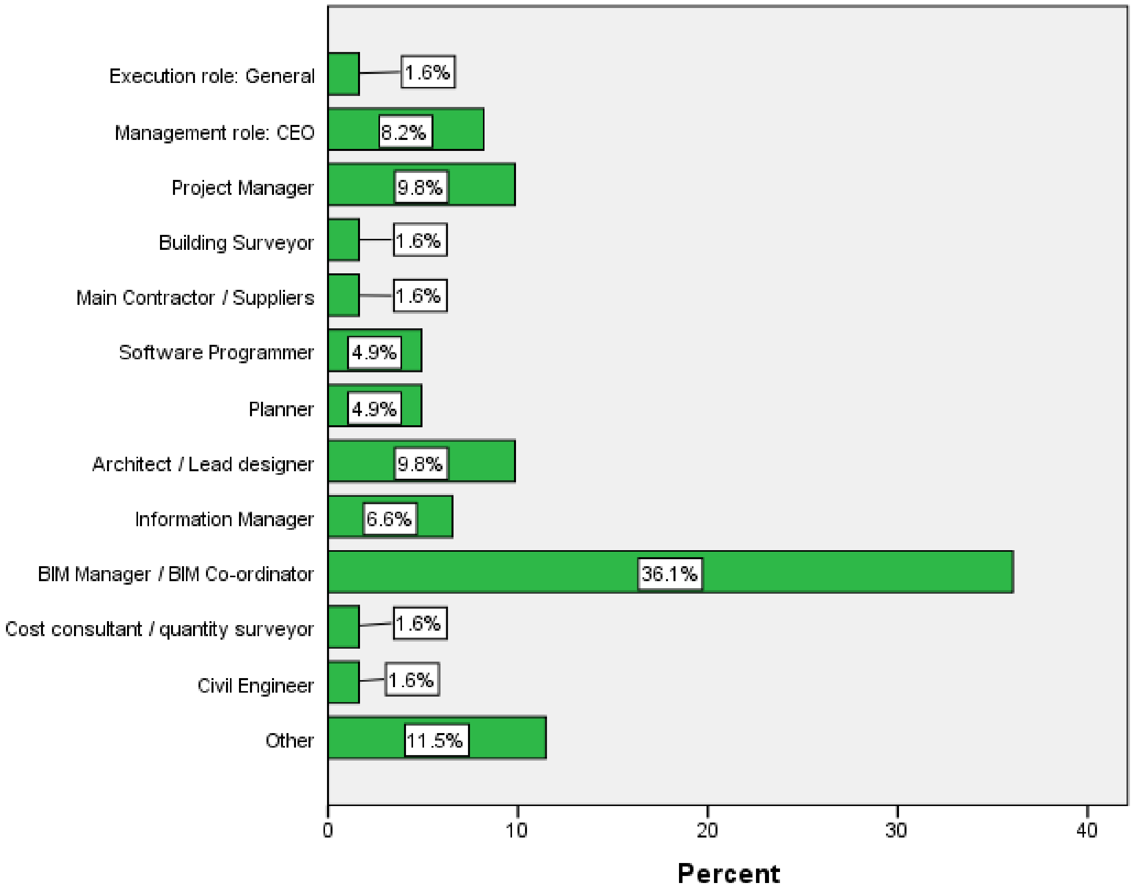

Figure 5.2: Occupation role of a transpose bar (Q1a)

Q1a is an occupation role in Figure 5.2– 100% responses to these questions was obtained. The majority of the respondents are BIM Managers / BIM Co-ordinators and related positions (36.1%), followed by Project Managers (9.8%) and Architect / Lead designer (9.8%) representing 55.7% of respondents. A minority is positioned as CEO (8.2%), Information Manger (6.6%), Software Programme (4.9%), Planner (4.9%), General (1.6%), Main Contractor / Suppliers (1.6%) Building Surveyor (1.6%), Cost consultant / quality surveyor (1.6%) and Civil Engineer (1.6%). Other various 6 positions represent (11.5%) of respondents.

Table 5.3: Q1a plus Q2b in the cross tabulation

Number of years working in the industry		Q2b (Number of years working in the industry)					**Total**
		0-2	2-4	4-10	10-15	More than 15 years	
Q1a	Execution role: General	0	0	0	0	1	**1**
	Management role: CEO	0	1	2	0	2	**5**
	Project Manager	0	1	1	3	1	**6**
	Building Surveyor	0	0	0	0	1	**1**
	Main Contractor / Suppliers	0	0	0	1	0	**1**
	Software Programmer	0	0	2	0	1	**3**
	Planner	0	1	0	1	1	**3**
	Architect / Lead designer	0	2	3	0	1	**6**
	Information Manager	0	0	1	1	2	**4**
	BIM Manager / BIM Co-ordinator	0	1	5	9	7	**22**
	Cost consultant / quantity surveyor	0	1	0	0	0	**1**
	Civil Engineer	0	0	0	0	1	**1**
	Other	1	2	1	0	3	**7**
Total		**1**	**9**	**15**	**15**	**21**	**61**

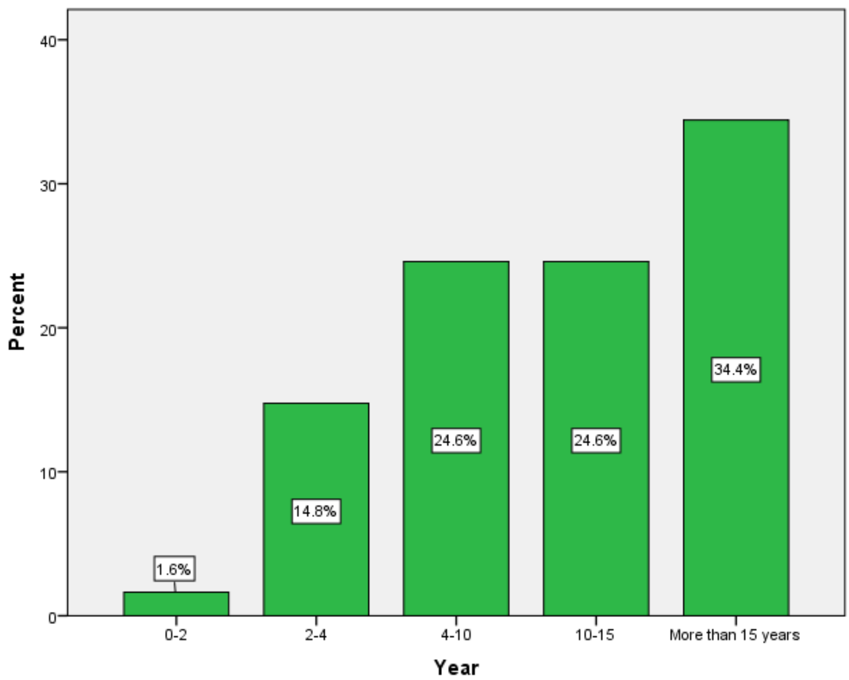

Figure 5.3: Number of years working in the industry (Q2b)

Q2b is the number of years working in the industry in Figure 5.3 – the most frequent in the sample were companies with more than 15 years in the industry (34.4%), followed by those that have been in the market for more than 10 years (24.6%) and these from 4-10 years (24.6%). In the last came the younger companies.

Proposing the role of majority of respondents as indicated under Q1a, with experience working in the industry over 10 and 15 years create some patterns of known a 4D BIM and their application were expected.

5.1.1.2 Company Information

Table 5.4: Frequencies for Q3a

Main project sources		Q3a (Main project sources)			
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Commercial	36	59.0	61.0	61.0
	Residential	4	6.6	6.8	67.8
	Highway	3	4.9	5.1	72.9
	Rail	6	9.8	10.2	83.1
	Other	10	16.4	16.9	100.0
	Total	**59**	**96.7**	**100.0**	
Missing	System	2	3.3		
Total		**61**	**100.0**		

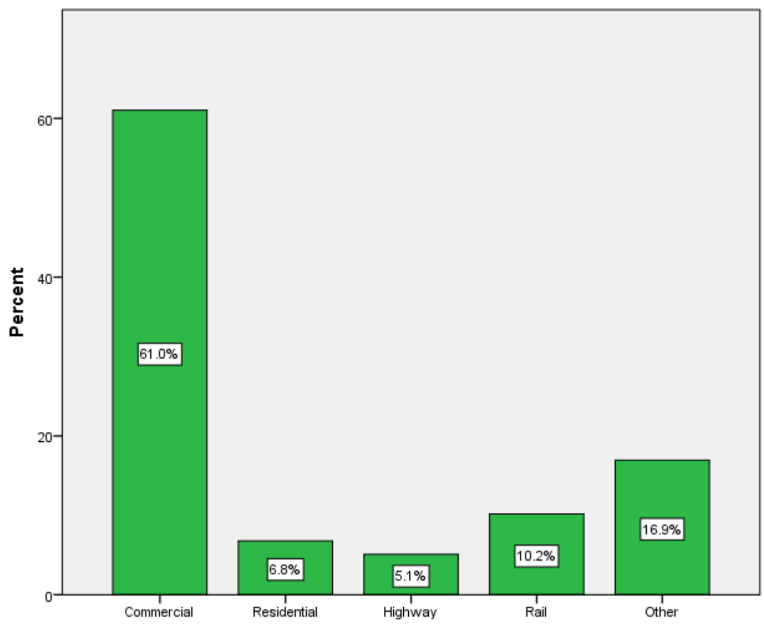

Figure 5.4: Main project sources (Q3a)

Q3a is the main project sources in Figure 5.4 – data indicates majority project sources as 61% were covered from the commercial site.

Table 5.5: Frequencies for Q4b

Number of company employees		Q4b (Number of company employees)			
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0-10	6	9.8	10.0	10.0
	10-20	4	6.6	6.7	16.7
	20-30	4	6.6	6.7	23.3
	30-40	7	11.5	11.7	35.0
	More than 50	39	63.9	65.0	100.0
	Total	**60**	**98.4**	**100.0**	
Missing	System	1	1.6		
Total		**61**	**100.0**		

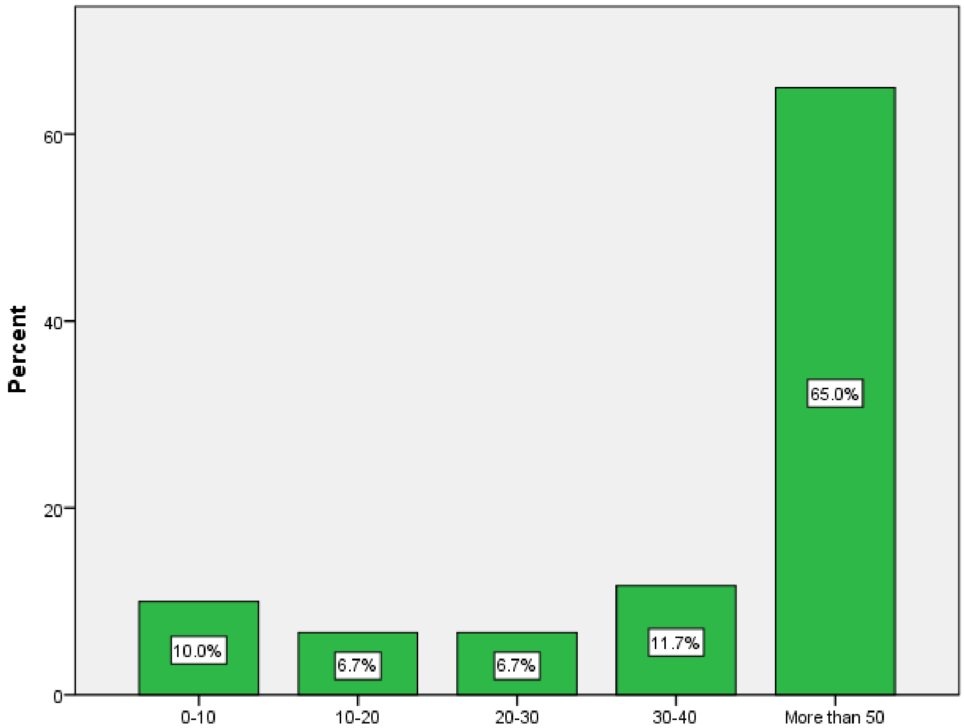

Figure 5.5: Number of company employees (Q4b)

Q4b is data indicates that the majority of respondents 65% are employees of the companies above 50 people employed.

Table 5.6: Q1a plus Q5c in the cross tabulation

Have you used BIM on any projects you have worked on?		**Q5c**		**Total**
		Yes	No	
Q1a	Execution role: General	1	0	**1**
	Management role: CEO	4	1	**5**
	Project Manager	6	0	**6**
	Building Surveyor	1	0	**1**
	Main Contractor / Suppliers	1	0	**1**
	Software Programmer	3	0	**3**
	Planner	1	2	**3**
	Architect / Lead designer	6	0	**6**
	Information Manager	4	0	**4**
	BIM Manager / BIM Co-ordinator	22	0	**22**
	Cost consultant / quantity surveyor	0	1	**1**
	Civil Engineer	0	1	**1**
	Other	7	0	**7**
Total		**56**	**5**	**61**

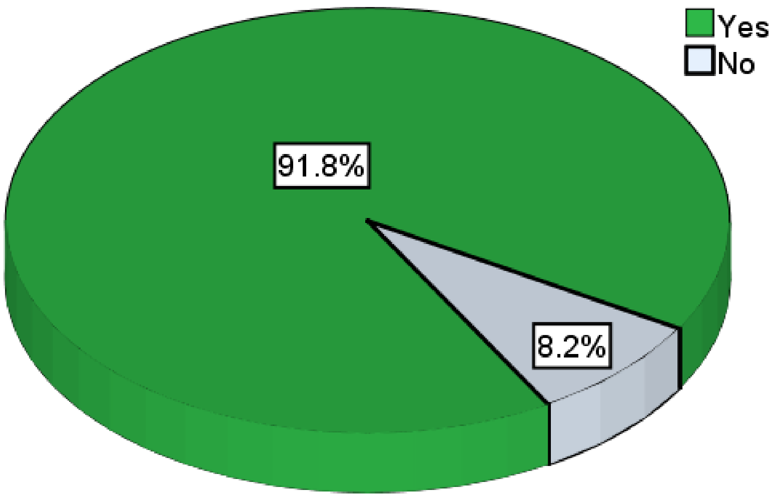

Figure 5.6: Working on BIM projects in a pie chart (Q5c)

Majority of respondents (91.8%) have been using BIM on the projects they worked on. As pattern the same companies have experience on BIM Level 2 mostly if not than Level 1 and they have employed more than 50 people.

Table 5.7: Q6d in the frequency for No and Yes

Level BIM		Q6d		Total
		No	Yes	
Q6d	Level 0 BIM	43	18	**61**
	Level 1 BIM	30	31	**61**
	Level 2 BIM	15	46	**61**

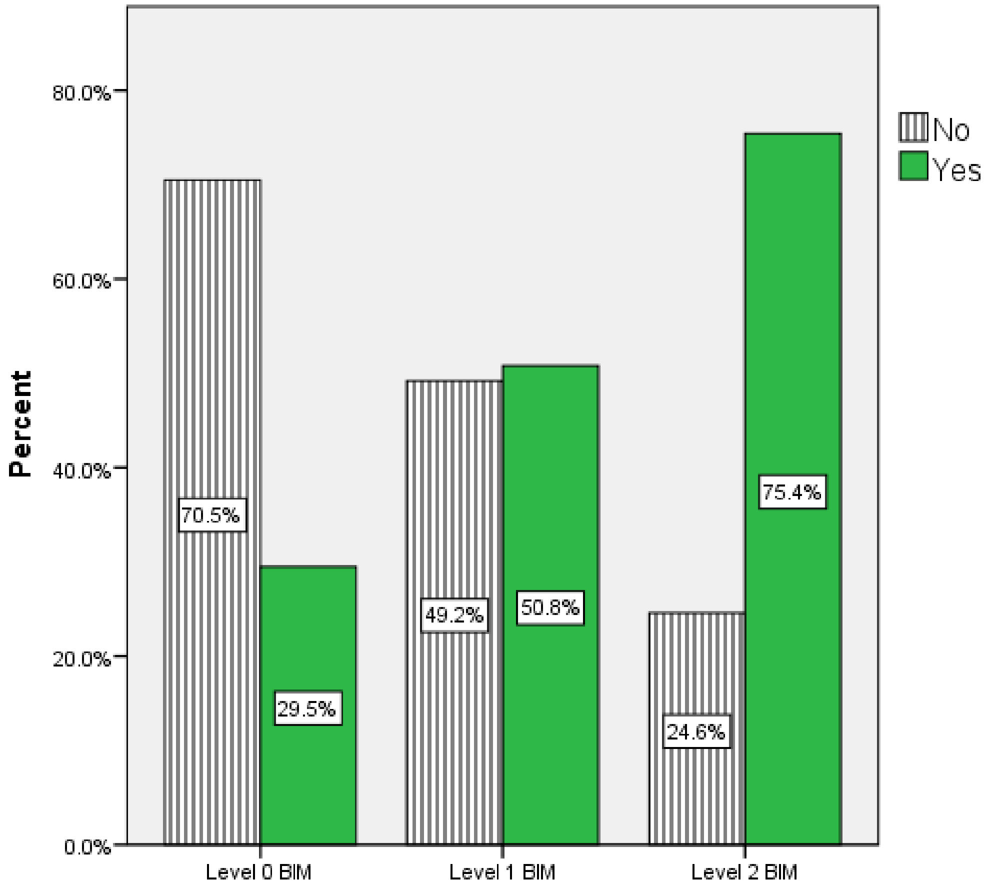

Figure 5.7: Level BIM in a bar chart (Q6d)

Data indicates that the majority of respondents (75.4%) have been using Level 2 BIM followed by 50.8% of respondents using Level 1 BIM and 29.5% of Level 0 BIM.

Table 5.8: Q7e in the frequency for No and Yes

Type of CAD/BIM software		Q7e		Total
		No	Yes	
Q7e	AutoCAD	16	45	**61**
	Revit	11	50	**61**
	Navisworks	15	46	**61**
	3D Max	38	23	**61**
	SketchUp	38	23	**61**
	Tekla	43	18	**61**
	ArchiCAD	51	10	**61**
	Synchro PRO	29	32	**61**
	Virtual Construction	57	4	**61**
	Visual Simulation	58	3	**61**
	MicroStation	42	19	**61**
	Project Wise Navigator	48	13	**61**
	Other	38	23	**61**

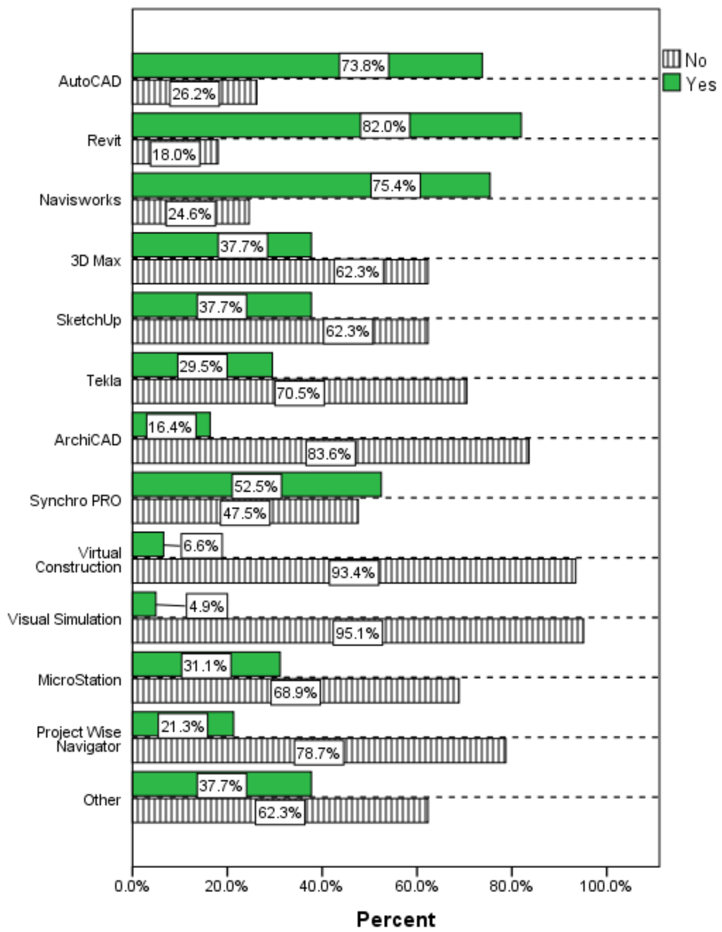

Figure 5.8: Type of CAD/BIM software (Q7e) in a transpose bar

Q7e shows the survey indicates in Figure 5.8 that the most used CAD/BIM software in the respondents' companies are Autodesk AutoCAD, Revit and Navisworks with 82% to 75% and 52.5% followed by Synchro Software Ltd. Synchro PRO while 37.7% of usage is shared with variety of other software.

Table 5.9: Q1a plus Q8f in the cross tabulation

The company implemented BIM for how long		**Q8f**				**Total**
		Have yet to implement	0-1 (year)	1-3 (years)	3-5 (years)	
Q1a	Execution role: General	0	0	0	1	1
	Management role: CEO	1	0	0	4	5
	Project Manager	0	0	2	4	6
	Building Surveyor	0	0	0	1	1
	Main Contractor / Suppliers	0	0	0	1	1
	Software Programmer	0	1	0	2	3
	Planner	2	0	0	1	3
	Architect / Lead designer	0	1	3	2	6
	Information Manager	0	0	1	3	4
	BIM Manager / BIM Co-ordinator	1	1	6	14	22
	Cost consultant / quantity surveyor	1	0	0	0	1
	Civil Engineer	1	0	0	0	1
	Other	0	0	0	7	7
Total		**6**	**3**	**12**	**40**	**61**

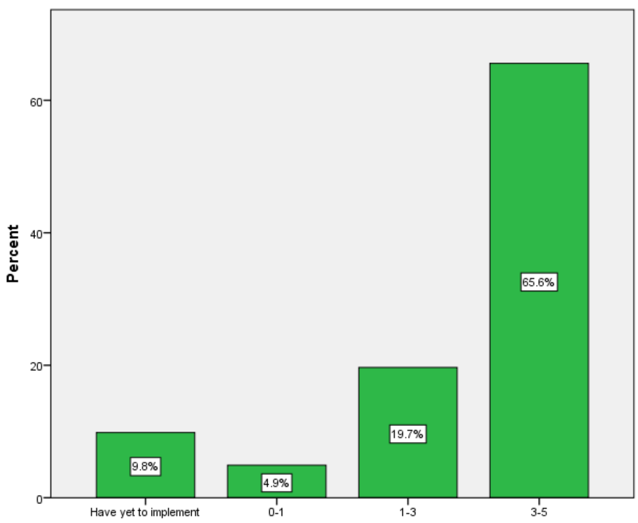

Figure 5.9: Q8f in a bar chart

The record in the Figure 5.9 shows the majority of respondents 65.6% are from companies which were implementing BIM in period from 3-5 years, followed by companies with 19.7% used BIM in practice from 1-3 years while 9.8% shows companies that never implemented BIM or it was for a short period from 0-1 years.

Table 5.10: Q1a plus Q9g in the cross tabulation

Planning software is used		Q9g				Total
		Primavera	Asta Powerproject	Microsoft-Project	Other	
Q1a	Execution role: General	0	1	0	0	**1**
	Management role: CEO	0	1	1	3	**5**
	Project Manager	2	1	3	0	**6**
	Building Surveyor	1	0	0	0	**1**
	Main Contractor / Suppliers	1	0	0	0	**1**
	Software Programmer	0	0	1	2	**3**
	Planner	2	1	0	0	**3**
	Architect / Lead designer	0	0	2	4	**6**
	Information Manager	1	0	2	1	**4**
	BIM Manager / BIM Co-ordinator	7	8	6	1	**22**
	Cost consultant / quantity surveyor	0	0	1	0	**1**
	Civil Engineer	0	0	1	0	**1**
	Other	3	0	1	3	**7**
Total		**17**	**12**	**18**	**14**	**61**

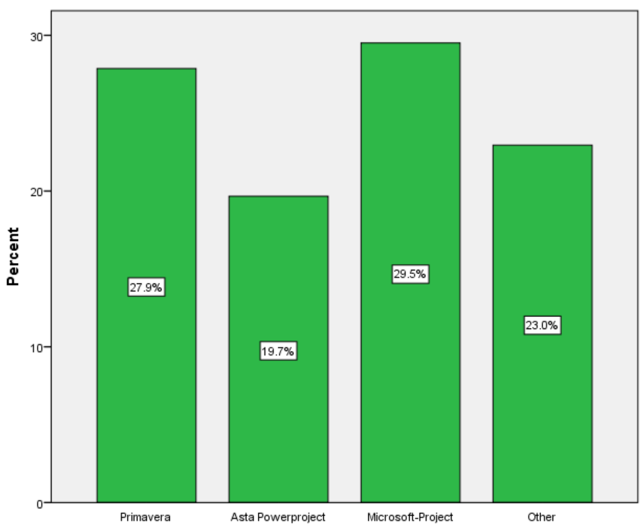

Figure 5.10: Q9g in a bar chart

The record in Figure 5.10 specifies Other are Synchro PRO, Microsoft Excel and various planning software in companies with 23%. Microsoft Project is the most commonly used by respondents with 29.5% as Primavera (27.9% respectively), followed by Asta Powerproject software with 19.7%.

5.1.1.3 Dynamic / 4D Modelling

Table 5.11: Q1a plus Q9g in the cross tabulation

4D BIM on the projects		**Q10a** No	Yes	Other	**Total**
Q1a	Execution role: General	1	0	0	**1**
	Management role: CEO	2	3	0	**5**
	Project Manager	2	4	0	**6**
	Building Surveyor	1	0	0	**1**
	Main Contractor / Suppliers	0	1	0	**1**
	Software Programmer	0	3	0	**3**
	Planner	2	1	0	**3**
	Architect / Lead designer	6	0	0	**6**
	Information Manager	1	3	0	**4**
	BIM Manager / BIM Co-ordinator	4	17	1	**22**
	Cost consultant / quantity surveyor	1	0	0	**1**
	Civil Engineer	1	0	0	**1**
	Other	0	6	1	**7**
Total		**21**	**38**	**2**	**61**

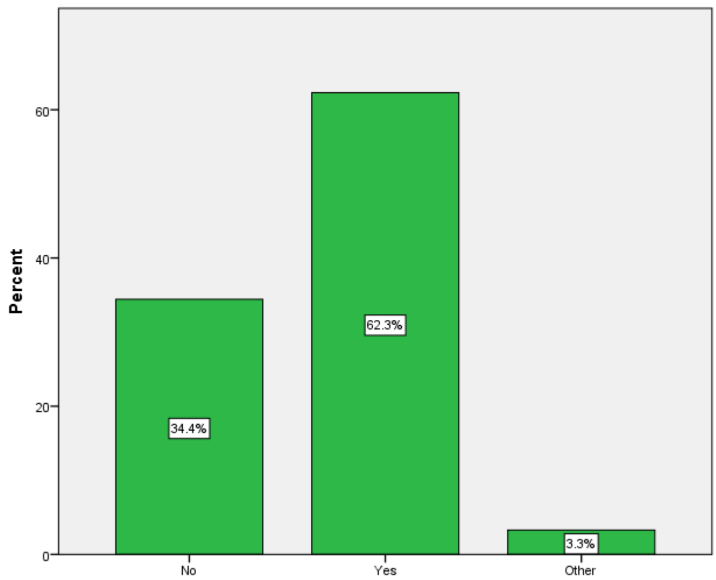

Figure 5.11: Q10a in a bar chart

The survey data indicates in Figure 5.11 that the majority 62.3% of the respondents have used 4D BIM in the projects where they have worked on.

Table 5.12: Q11b in the frequency for No and Yes

4D BIM in the projects are used for:		**Q11b**		**Total**
		Yes	No	
Q11b	Communicating the plan to client	34	27	**61**
	As part of the project planning phase	34	27	**61**
	Communicating between contractors / subcontractors	26	35	**61**
	Site logistics / space planning	29	32	**61**
	Site safety briefings	16	45	**61**
	Toolbox talks	8	53	**61**
	Work package conflict detection	16	45	**61**
	Other	9	52	**61**

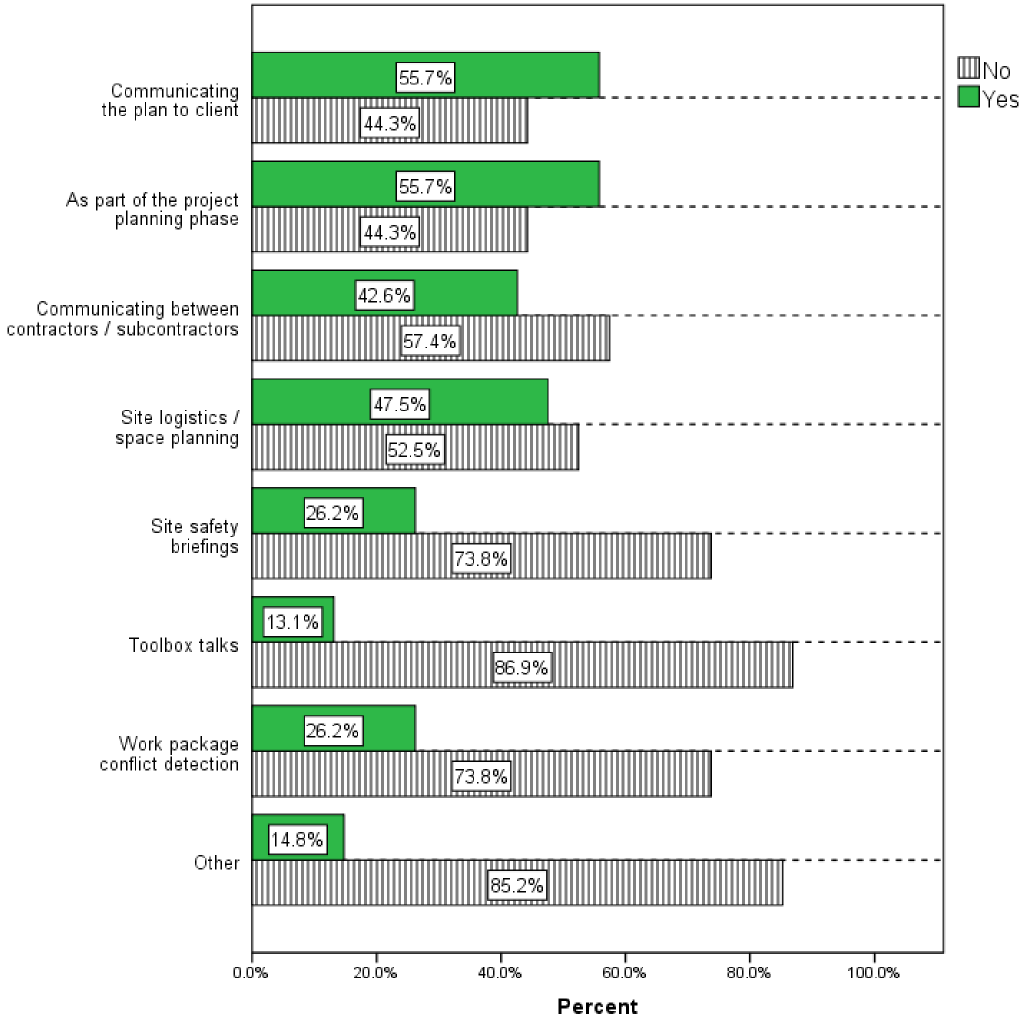

Figure 5.12: Q11b in a transpose bar

The survey data in Figure 5.12 indicates that 4D BIM projects were mostly used for communicating the plan to the client and as part of the project planning phase with the same percent of 55.7%, followed by for site logistics/space planning with 47.5% and for Communicating between contractors/subcontractors as 42.6%, while 26.2% of respondents indicated that 4D BIM was used in projects for work package conflict detection and site safety briefings.

Table 5.13: Q1a plus Q12c in the cross tabulation

Who was responsible for creating the 4D models		Q12c					**Total**
		Project manager	Project planner	CAD / BIM Technician	Other	N/A	
Q1a	Execution role: General	0	0	1	0	0	**1**
	Management role: CEO	1	1	2	1	0	**5**
	Project Manager	0	0	3	1	2	**6**
	Building Surveyor	0	1	0	0	0	**1**
	Main Contractor / Suppliers	0	1	0	0	0	**1**
	Software Programmer	0	2	1	0	0	**3**
	Planner	0	1	0	0	2	**3**
	Architect / Lead designer	0	0	0	0	6	**6**
	Information Manager	0	1	1	1	1	**4**
	BIM Manager / BIM Co-ordinator	0	4	9	6	3	**22**
	Cost consultant / quantity surveyor	0	0	1	0	0	**1**
	Civil Engineer	0	0	1	0	0	**1**
	Other	0	2	1	4	0	**7**
Total		**1**	**13**	**20**	**13**	**14**	**61**

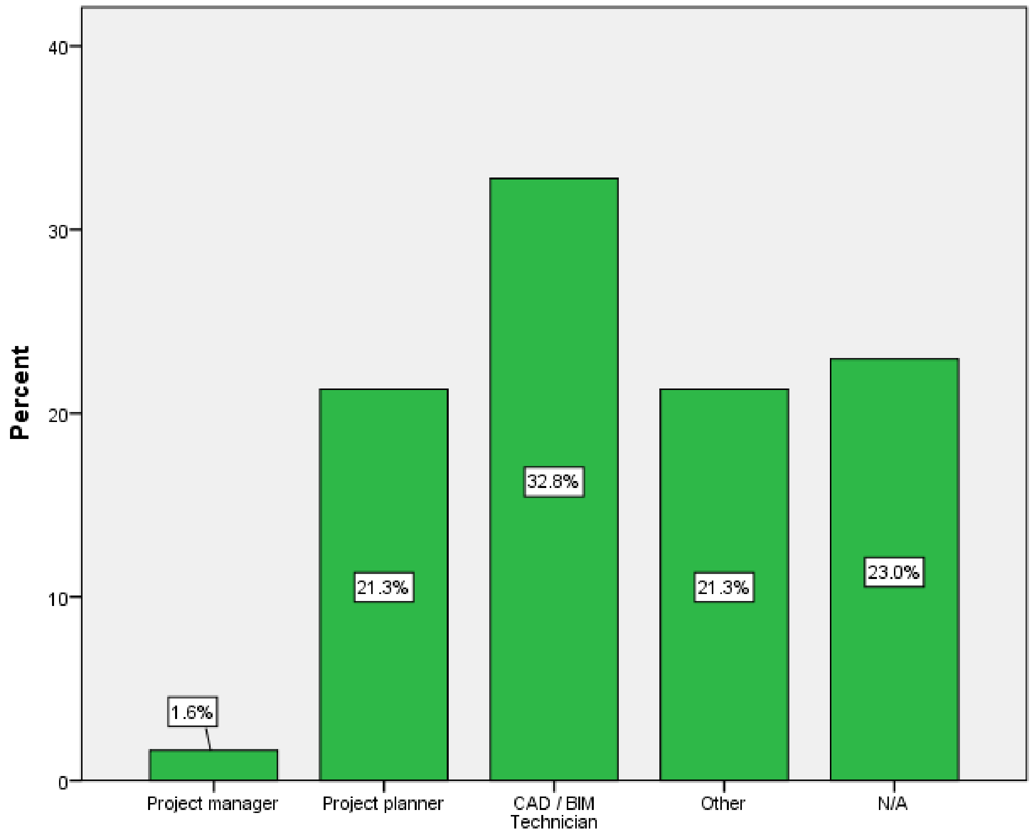

Figure 5.13: Q12c in a bar chart

Q12c is the survey shows the majority respondents indicated that 32.8% of responsibilities are given to CAD/BIM Technician for creating the 4D models in their companies while 21.3% of the responsibilities are with the related Project Planner and 1.6% of the Project Manager. 21.3% was dedicated to “Others” with various positions of specialists and consultants.

Table 5.14: Q1a plus Q13d in the cross tabulation

Who should be responsible for creating a 4D model?		Q13d: Project manager	Q13d: Project planner	Q13d: CAD / BIM Technician	Q13d: Other	Q13d: N/A	**Total**
Q1a	Execution role: General	0	0	1	0	0	**1**
	Management role: CEO	2	2	1	0	0	**5**
	Project Manager	0	2	1	2	1	**6**
	Building Surveyor	0	1	0	0	0	**1**
	Main Contractor / Suppliers	0	1	0	0	0	**1**
	Software Programmer	0	1	0	2	0	**3**
	Planner	0	1	2	0	0	**3**
	Architect / Lead designer	0	3	2	0	1	**6**
	Information Manager	1	3	0	0	0	**4**
	BIM Manager / BIM Co-ordinator	0	11	3	6	2	**22**
	Cost consultant / quantity surveyor	0	1	0	0	0	**1**
	Civil Engineer	1	0	0	0	0	**1**
	Other	0	2	1	4	0	**7**
Total		**4**	**28**	**11**	**14**	**4**	**61**

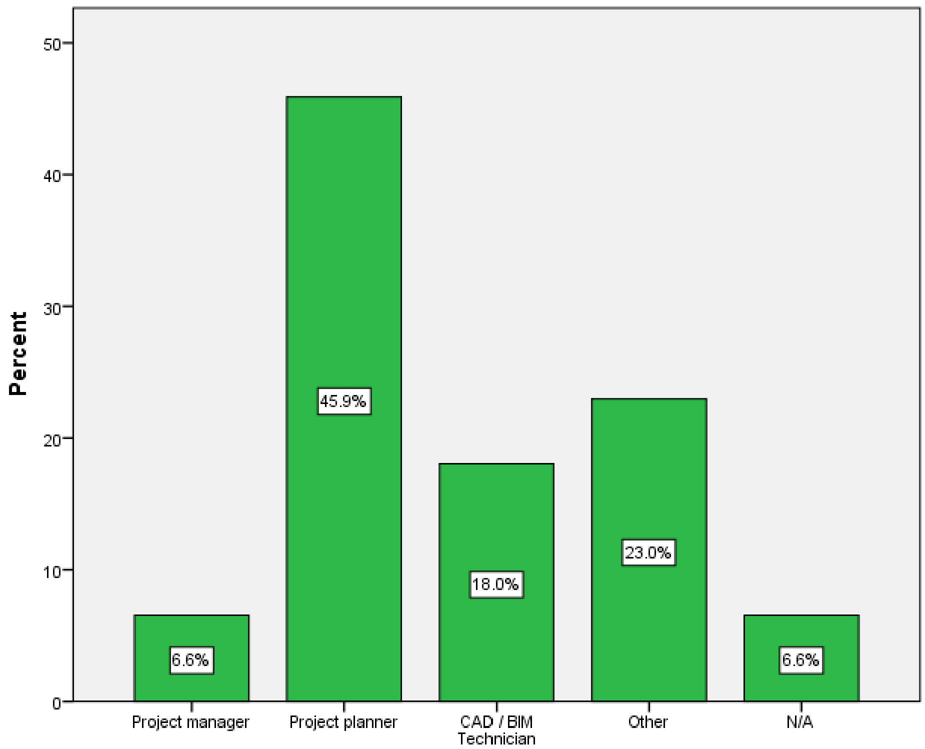

Figure 5.14: Q13d in a bar chart

The record in Figure 5.14 indicates that the majority of the respondents are in opinion (45.9%) that the Project Planners should be responsible for creating a 4D model while 18% and 6.6% are related to positions of CAD/BIM Technician and the Project Managers respectfully. Followed Others have various details as well as the percent 23 and four respondents (6.6%) do not know who should be responsible for creating a 4D model.

Table 5.15: Q1a plus Q14e in the cross tabulation

If previously used 4D BIM on projects, how often did the simulation show changes to the project. Every…		**Q14e**							**Total**
		1 hour	1 day	2 days	1 week	1 month	Other	N/A	
Q1a	Execution role: General	0	0	0	0	0	0	1	**1**
	Management role: CEO	1	1	0	1	0	1	1	**5**
	Project Manager	0	0	0	3	1	0	2	**6**
	Building Surveyor	0	0	0	0	0	0	1	**1**
	Main Contractor / Suppliers	0	0	0	0	1	0	0	**1**
	Software Programmer	0	1	0	0	1	1	0	**3**
	Planner	0	0	0	1	0	0	2	**3**
	Architect / Lead designer	0	0	0	0	1	0	5	**6**
	Information Manager	0	0	0	2	1	0	1	**4**
	BIM Manager / BIM Co-ordinator	2	2	0	9	4	2	3	**22**
	Cost consultant / quantity surveyor	0	0	0	0	0	0	1	**1**
	Civil Engineer	0	0	1	0	0	0	0	**1**
	Other	0	3	1	2	0	1	0	**7**
Total		**3**	**7**	**2**	**18**	**9**	**5**	**17**	**61**

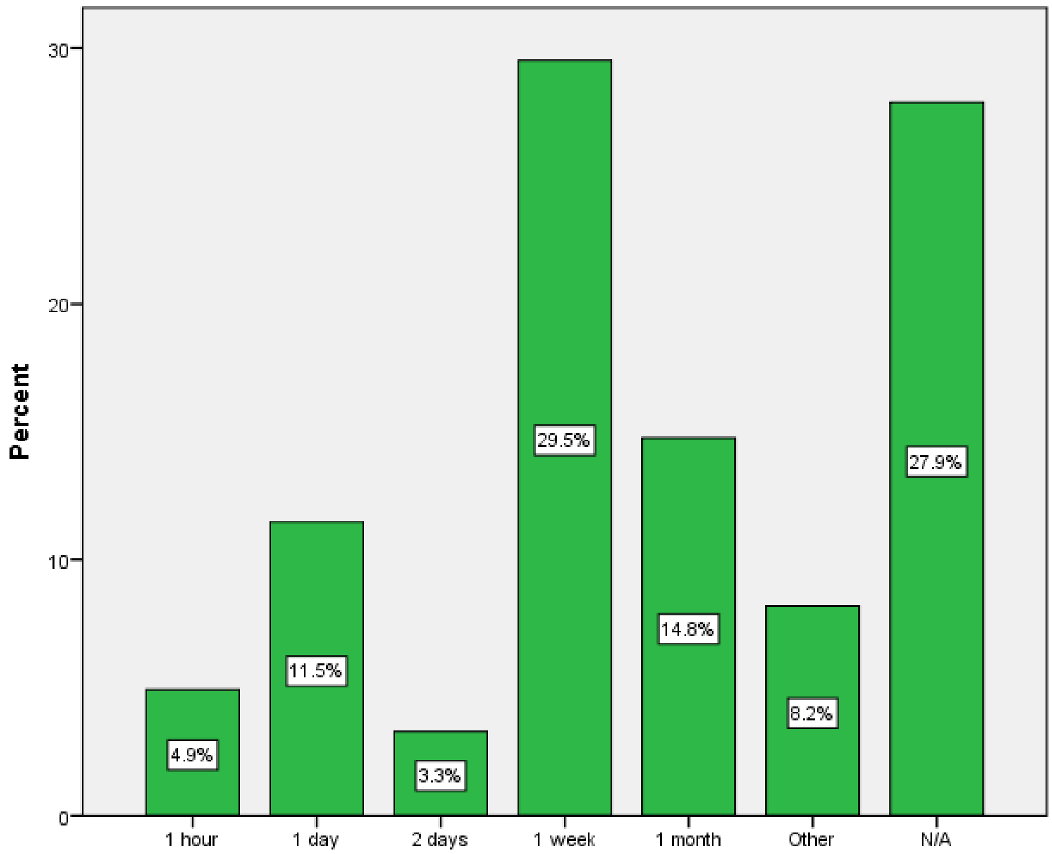

Figure 5.15: Q14e in a bar chart

The record says that 29.5% of respondents have indicated every week the simulation shows the changes to the project, while 14.8% were indicated to period for every month respectfully and every day with 11.5%. Three respondents have hourly with 4.9%. Only 3.3% was dedicated to two days simulation changes. Others have various times and details and followed the percent is 8.2%. The problems of N/A are not able to use 4D BIM and do not know how to change times to the projects. Nine respondents of BIM Managers / BIM Co-ordinators and three respondents of Project Managers have used 4D BIM to change every week.

Table 5.16: Q1a plus Q15f in the cross tabulation

Who has been responsible for specifying how often the simulation showed changes to the projects?		**Q15f** Planner	BIM Manager / BIM Co-ordinator	Project Manager	Answer	None	**Total**
Q1a	Execution role: General	0	0	0	0	1	**1**
	Management role: CEO	2	0	1	0	2	**5**
	Project Manager	1	0	2	0	3	**6**
	Building Surveyor	0	0	0	0	1	**1**
	Main Contractor / Suppliers	1	0	0	0	0	**1**
	Software Programmer	0	0	0	2	1	**3**
	Planner	0	0	1	0	2	**3**
	Architect / Lead designer	0	0	1	0	5	**6**
	Information Manager	1	1	0	1	1	**4**
	BIM Manager / BIM Co-ordinator	3	2	5	7	5	**22**
	Cost consultant / quantity surveyor	1	0	0	0	0	**1**
	Civil Engineer	0	0	0	1	0	**1**
	Other	3	0	0	3	1	**7**
Total		**12**	**3**	**10**	**14**	**22**	**61**

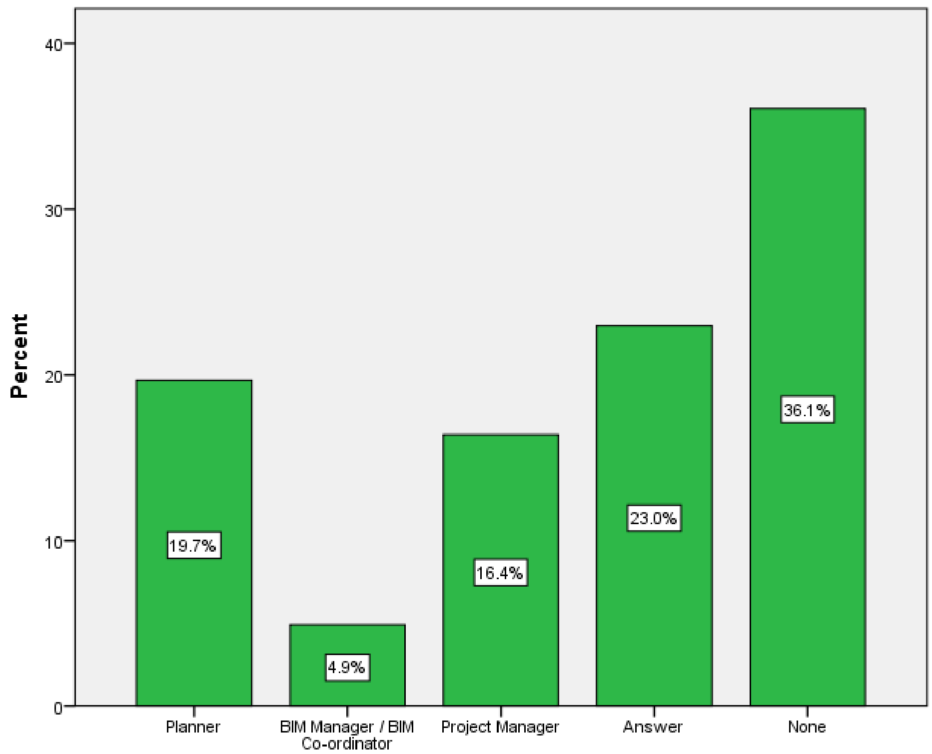

Figure 5.16: Q15e in a bar chart

Table 5.17: Q15f answers

Q1a (Roles)	**Q10a (4D BIM)**	**Q15f – 14 respondents answer**
BIM Manager / BIM Co-ordinator	Yes	*“Information Manager”*
BIM Manager / BIM Co-ordinator	Yes	*“Collective review with the Senior Management Team, with input of the lead project planner, project manager and design manager.”*
BIM Manager / BIM Co-ordinator	Yes	*“Depends on the task and what we are trying to achieve - possession work can be very intense, hourly is very common for management and proof of method in advance of works. Can be used for live re-planning (not too often). Occasionally used for long range logistical planning (i.e. large programme over operational assets - or overlapping programmes of work.”*
BIM Manager / BIM Co-ordinator	Yes	*“Our company, as those responsible for M&E coordination, it is critical that all of the information we have is current, therefore when federating newly received models and using Solibri Model Comparison & Navis Manage to check for changes we are often the first to know that a change has taken place, in other instances a design change report will have been raised to which we will act on. On a number of project a lot of changes can be missed if not communicated effectively.”*
BIM Manager / BIM Co-ordinator	Yes	*“Combination of planning team and project leadership team”*
BIM Manager / BIM Co-ordinator	Yes	*“The Client in collaboration with the Lead Designer”*
BIM Manager / BIM Co-ordinator	Yes	*“The consultant as it was just indicative from the design point of view and not from a buildability point of view.”*
Information Manager	Yes	*“Contractor”*
Civil Engineer	No	*“MD (Managing Director)”*
Software Programmer	Yes	*“Consultant”*
Software Programmer	Yes	*“Whenever it can done, it usually gets less and less often as the project progresses.”*
Other - Director of Product Management (Software)	Yes	*“Daily planning (Planner), Weekly updates (Planner, Project Manager, Construction Manager) and Monthly updates (Contract, Client”*
Other - Digital Engineer	Other	*“Digital Engineering Team”*
Other - Senior VDC	Yes	*“Construction team”*

The question in Figure 5.16 has attracted open ended responses where each respondent listed down many positions. In order to conclude, the responses were grouped showing 19.7% of nine respondents are in opinion that Planners were responsible for specifying how often the simulation should change the project, followed by 16.4% for Project Manager and 4.9% for BIM Manager / BIM Co-ordinator. Above the percent of Answers with the 23 percent while having different 14 answers in Table 5.17. None with negatively 36.1% are inconclusive and irrelevant because Architects and Planners do not have any experience with 4D BIM and who creates the simulation to the project is responsible.

Table 5.18: Q1a plus Q16g in the cross tabulation

Should single elements in the 3D models be subdivided into smaller sub-elements of the models to show more detail during the 4D simulation.		**Q16g**				**Total**
		Yes	No	Sometimes	Don't know	
Q1a	Execution role: General	1	0	0	0	**1**
	Management role: CEO	1	1	3	0	**5**
	Project Manager	1	0	3	2	**6**
	Building Surveyor	1	0	0	0	**1**
	Main Contractor / Suppliers	0	0	1	0	**1**
	Software Programmer	3	0	0	0	**3**
	Planner	3	0	0	0	**3**
	Architect / Lead designer	3	0	2	1	**6**
	Information Manager	1	0	3	0	**4**
	BIM Manager / BIM Co-ordinator	4	2	15	1	**22**
	Cost consultant / quantity surveyor	0	0	1	0	**1**
	Civil Engineer	1	0	0	0	**1**
	Other	3	0	4	0	**7**
Total		**22**	**3**	**32**	**4**	**61**

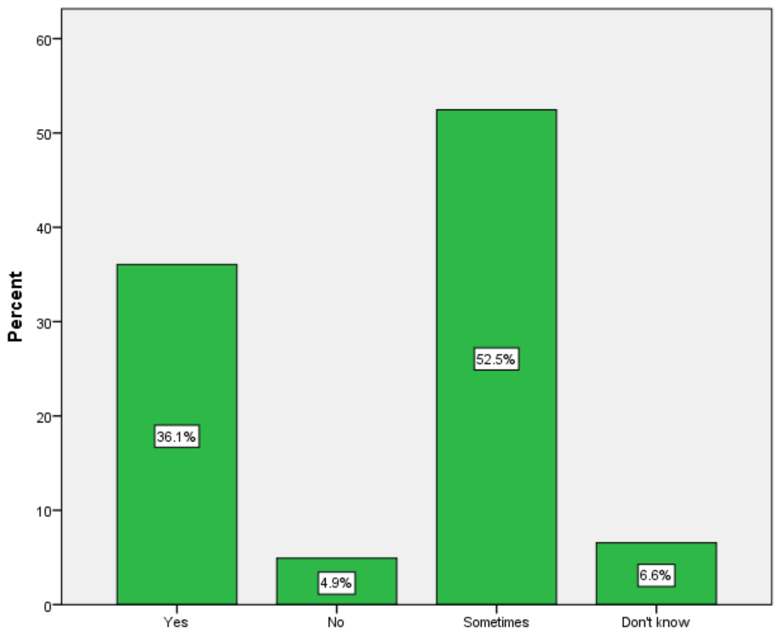

Figure 5.17: Q16g in a bar chart

The record in bar chart for Q16g indicates in Figure 5.17 that 52.5% of respondents are in opinion that only sometimes 3D model should be sub-divided into smaller elements of the model in order to show more details during the 4D simulation, followed by 46.1% of respondents with the confirmation opinion as "yes" and leaving 6.6% of respondents who do not know anything about needs of sub-dividing the elements and 4.9% of respondents do not believe in the subdivision of the elements.

Table 5.19: Q1a plus Q17h in the cross tabulation

Can 4D model with more details and shorter time period between model changes, improve identification of potential conflicts and clashes?		**Q17h**			**Total**
		Yes	No	Don't know	
Q1a	Execution role: General	1	0	0	**1**
	Management role: CEO	5	0	0	**5**
	Project Manager	4	0	2	**6**
	Building Surveyor	1	0	0	**1**
	Main Contractor / Suppliers	0	0	1	**1**
	Software Programmer	3	0	0	**3**
	Planner	2	1	0	**3**
	Architect / Lead designer	5	0	1	**6**
	Information Manager	3	1	0	**4**
	BIM Manager / BIM Co-ordinator	18	3	1	**22**
	Cost consultant / quantity surveyor	1	0	0	**1**
	Civil Engineer	1	0	0	**1**
	Other	7	0	0	**7**
Total		**51**	**5**	**5**	**61**

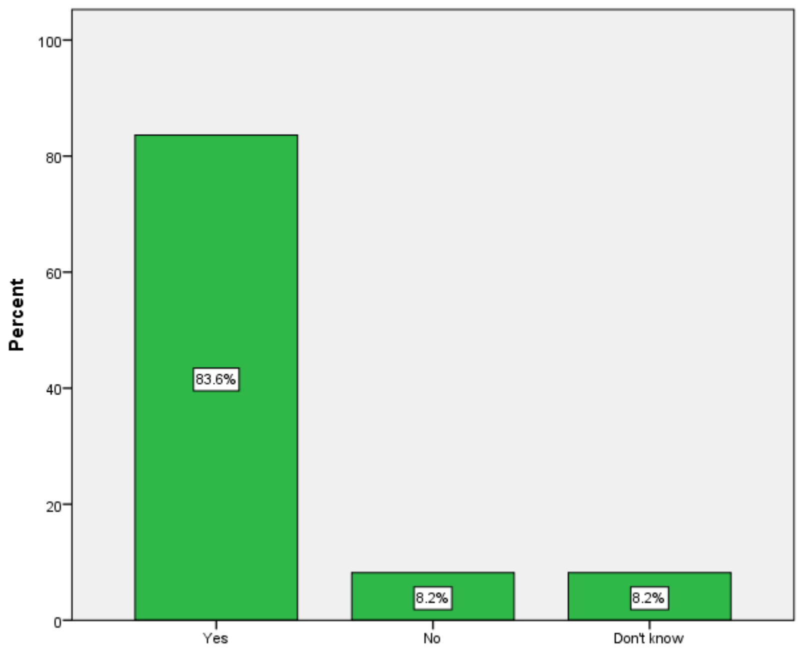

Figure 5.18: Q17h in a bar chart

The record of Q17h indicates in Figure 5.18 that the majority of respondents 83.6% do agree that if a 4D model shows more details it can improve the identification of potential conflicts and clashes. The remaining 8.2% of respondents are in disagreement or they do not know.

Table 5.20: Q1a plus Q18i in the cross tabulation

The ability to change the detail of the 4D model directly within the 4D software tool		**Q18i**			**Total**
		Yes	No	Don't know	
Q1	Execution role: General	1	0	0	**1**
	Management role: CEO	3	1	1	**5**
	Project Manager	3	2	1	**6**
	Building Surveyor	1	0	0	**1**
	Main Contractor / Suppliers	1	0	0	**1**
	Software Programmer	2	0	1	**3**
	Planner	1	1	1	**3**
	Architect / Lead designer	4	1	1	**6**
	Information Manager	2	2	0	**4**
	BIM Manager / BIM Co-ordinator	12	9	1	**22**
	Cost consultant / quantity surveyor	1	0	0	**1**
	Civil Engineer	1	0	0	**1**
	Other	5	1	1	**7**
Total		**37**	**17**	**7**	**61**

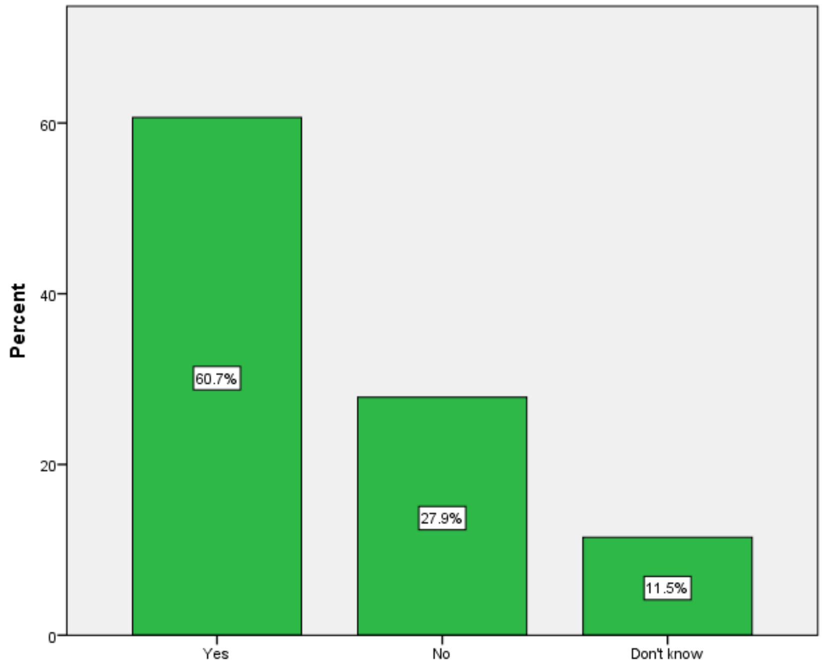

Figure 5.19: Q18i in a bar chart

The record in Figure 5.19 indicates that the majority of respondents (60.7%) are in the opinion of needs to have the ability to change the detail of the 4D model within the 4D software, followed by 27.9% of respondents who disagree and 11.5% of these who do not know.

5.1.1.4 Example Tasks

Q19-24 show example tasks (1-28) have construction time of tables and charts in detail how long a 4D model should be used for the building examples:

Table 5.21: Frequency and Percent for Q19 (1-5)

Example Tasks	Q19 (1-5)						Total
	N/A	Hourly	Daily	Two days	Weekly	Fortnight	
1. Site set up works	5	2	30	5	17	2	**61**
	8.2%	3.3%	49.2%	8.2%	27.9%	3.3%	**100.0%**
2. Foundation excavation	3	2	34	7	12	3	**61**
	4.9%	3.3%	55.7%	11.5%	19.7%	4.9%	**100.0%**
3. Piling operations	3	6	31	6	11	4	**61**
	4.9%	9.8%	50.8%	9.8%	18.0%	6.6%	**100.0%**
4. Foundation concrete pouring	3	5	32	7	11	3	**61**
	4.9%	8.2%	52.5%	11.5%	18.0%	4.9%	**100.0%**
5. Pile cap formation	4	4	30	5	14	4	**61**
	6.6%	6.6%	49.2%	8.2%	23.0%	6.6%	**100.0%**

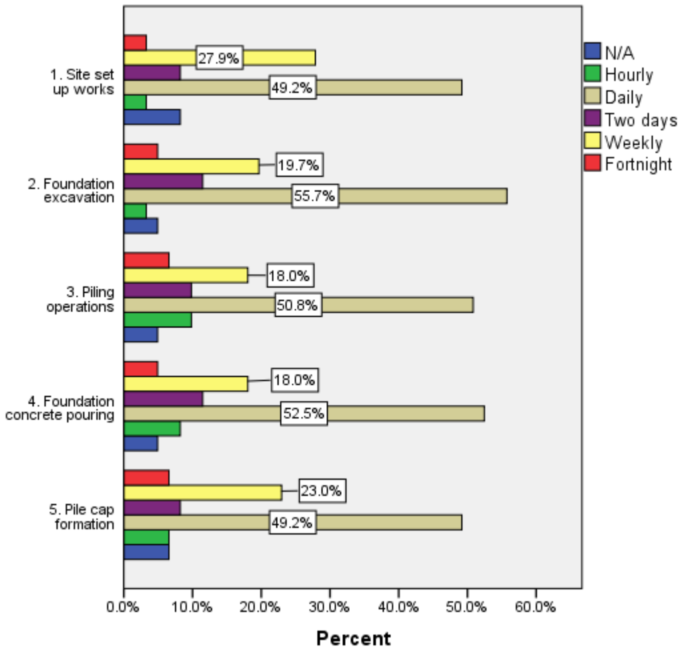

Figure 5.20: Percent bar chart for Q19 (1-5)

The record indicated that the majority of respondents in Figure 5.20 are in opinion that only on Daily basis (49.2%, 55.7%, 50.8%, 52.5%, 49.2%) the model should show changes, followed by Weekly with much lower values (27.9%, 19.7%, 18%, 18%, 23%).

Table 5.22: Frequency and Percent for Q20 (6-10)

Example Tasks	Q20 (6-10)						Total
	N/A	Hourly	Daily	Two days	Weekly	Fortnight	
6. Foundation concrete curing	6 9.8%	4 6.6%	25 41.0%	5 8.2%	18 29.5%	3 4.9%	**61** **100.0%**
7. Erection of formwork	4 6.6%	7 11.5%	29 47.5%	6 9.8%	13 21.3%	2 3.3%	**61** **100.0%**
8. Slab creation / concrete	4 6.6%	3 4.9%	31 50.8%	7 11.5%	15 24.6%	1 1.6%	**61** **100.0%**
9. Erection of steelwork / framing	3 4.9%	5 8.2%	35 57.4%	3 4.9%	13 21.3%	2 3.3%	**61** **100.0%**
10. Erection of concrete frame	3 4.9%	5 8.2%	30 49.2%	5 8.2%	16 26.2%	2 3.3%	**61** **100.0%**

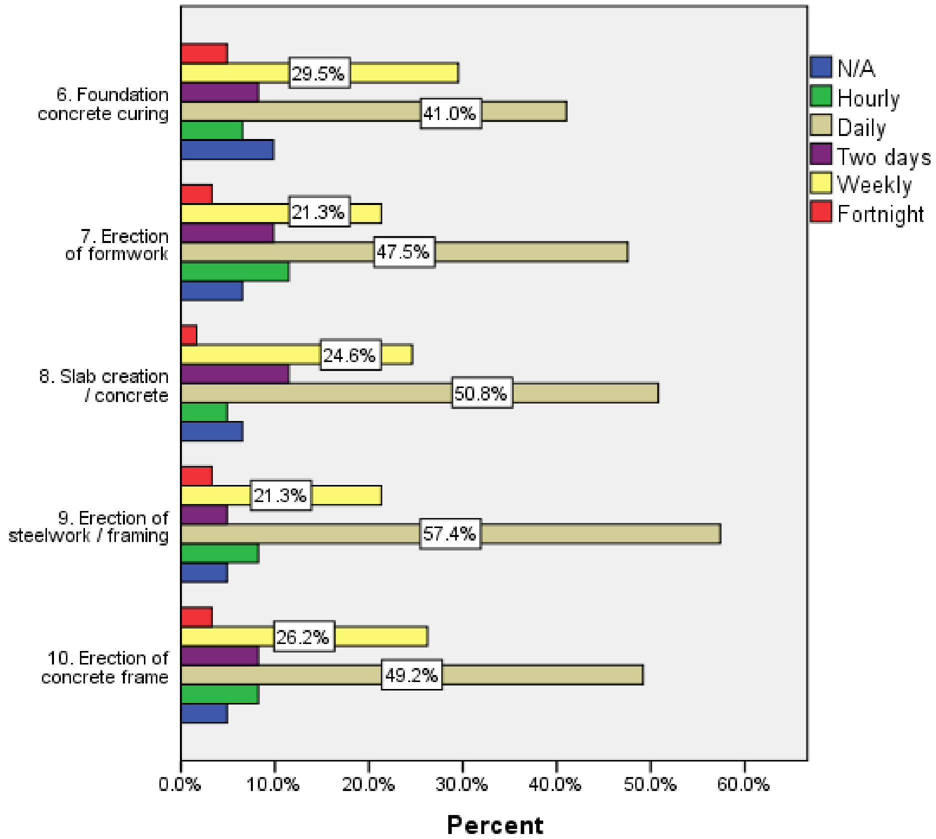

Figure 5.21: Percent bar chart for Q20 (6-10)

The record indicated that the majority of respondents in Figure 5.21 are in opinion that only on Daily basis (41%, 47.5%, 50.8%, 57.4%, 49.2%) the model should show changes, followed by Weekly with much lower values (29.5%, 21.3%, 24.6%, 21.3%, 26.2%).

Table 5.23: Frequency and Percent for Q21 (11-15)

Example Tasks	**Q21 (11-15)**						**Total**
	N/A	**Hourly**	**Daily**	**Two days**	**Weekly**	**Fortnight**	
11. External walls construction (masonry work)	4 6.6%	1 1.6%	30 49.2%	8 13.1%	16 26.2%	2 3.3%	**61** **100.0%**
12. Internal walls creation (masonry work)	4 6.6%	1 1.6%	29 47.5%	9 14.8%	16 26.2%	2 3.3%	**61** **100.0%**
13. Internal walls (other)	4 6.6%	2 3.3%	29 47.5%	9 14.8%	15 24.6%	2 3.3%	**61** **100.0%**
14. Erection of scaffold / temporary works	3 4.9%	4 6.6%	28 45.9%	10 16.4%	14 23.0%	2 3.3%	**61** **100.0%**
15. Installation of cladding systems	4 6.6%	4 6.6%	27 44.3%	9 14.8%	15 24.6%	2 3.3%	**61** **100.0%**

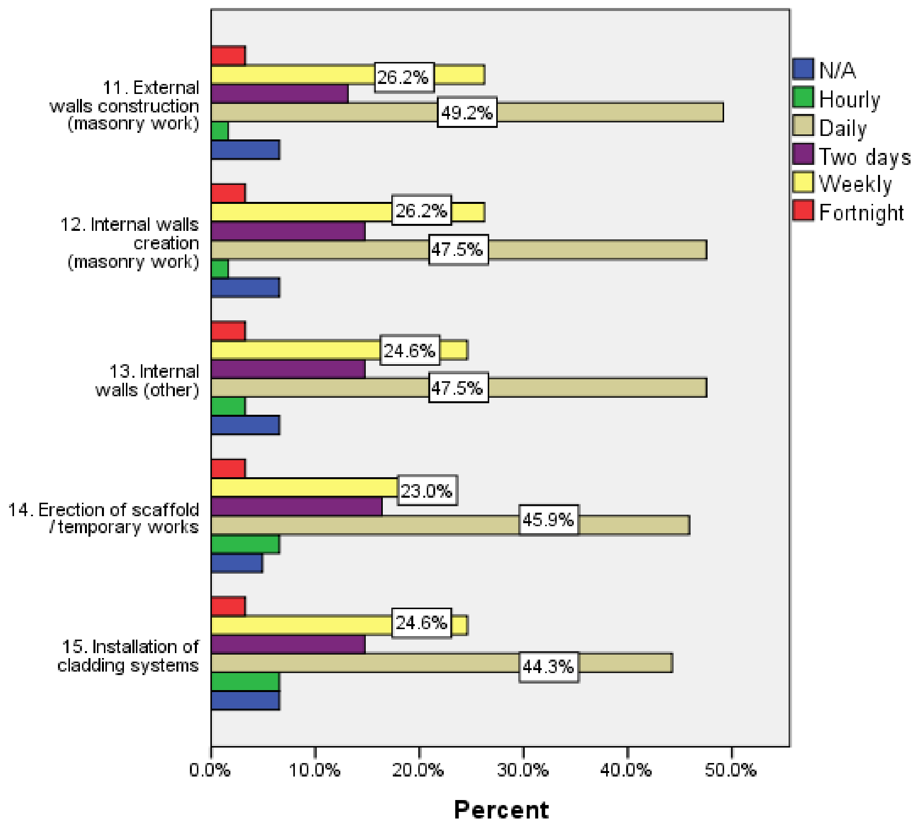

Figure 5.22: Percent transpose bar for Q21 (11-15)

The record indicated that the majority of respondents in Figure 5.22 are in opinion that only on Daily basis (49.2%, 47.5%, 47.5%, 45.9%, 44.3%) the model should show changes, followed by Weekly with much lower values (26.2%, 26.2%, 24.6%, 23%, 24.6%).

Table 5.24: Frequency and Percent for Q22 (16-20)

Example Tasks	**Q22 (16-20)**						**Total**
	N/A	**Hourly**	**Daily**	**Two days**	**Weekly**	**Fortnight**	
16. First fix electrical	5 8.2%	5 8.2%	23 37.7%	7 11.5%	17 27.9%	4 6.6%	**61** **100.0%**
17. Ventilation work / ductwork installation	4 6.6%	6 9.8%	22 36.1%	10 16.4%	16 26.2%	3 4.9%	**61** **100.0%**
18. Water supply installation	4 6.6%	6 9.8%	21 34.4%	9 14.8%	16 26.2%	5 8.2%	**61** **100.0%**
19. Door installation	5 8.2%	4 6.6%	27 44.3%	8 13.1%	14 23.0%	3 4.9%	**61** **100.0%**
20. Window installation	4 6.6%	4 6.6%	27 44.3%	7 11.5%	14 23.0%	5 8.2%	**61** **100.0%**

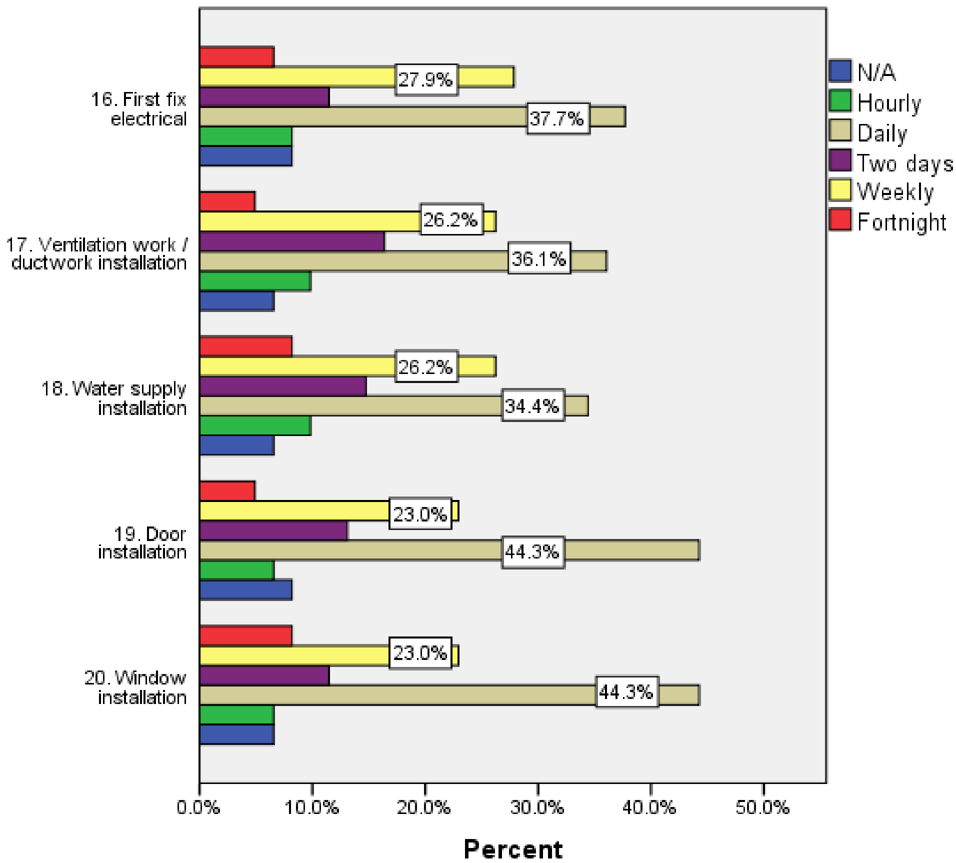

Figure 5.23: Percent transpose bar for Q22 (16-20)

The record indicated that the majority of respondents in Figure 5.23 are in opinion that only on Daily basis (37.7%, 36.1%, 34.4%, 44.3%, 44.3%,) the model should show changes, followed by Weekly with much lower values (27.9%, 26.2%, 26.2%, 23%, 23%).

Table 5.25: Frequency and Percent for Q23 (21-24) and Q24 (25-28)

Example Tasks	**Q23 (21-24) and Q24 (25-28)**						**Total**
	N/A	**Hourly**	**Daily**	**Two days**	**Weekly**	**Fortnight**	
21. Drainage activities	5 8.2%	6 9.8%	24 39.3%	6 9.8%	16 26.2%	4 6.6%	**61** **100.0%**
22. Insulation fixing / installation	9 14.8%	5 8.2%	22 36.1%	6 9.8%	16 26.2%	3 4.9%	**61** **100.0%**
23. Second fix electrical / ventilation / plumbing	6 9.8%	5 8.2%	23 37.7%	4 6.6%	19 31.1%	4 6.6%	**61** **100.0%**
24. External earthworks	3 4.9%	2 3.3%	24 39.3%	8 13.1%	20 32.8%	4 6.6%	**61** **100.0%**
25. Landscaping	3 4.9%	2 3.3%	18 29.5%	10 16.4%	22 36.1%	6 9.8%	**61** **100.0%**
26. External drainage	4 6.6%	2 3.3%	23 37.7%	7 11.5%	19 31.1%	6 9.8%	**61** **100.0%**
27. Elevator installation	5 8.2%	3 4.9%	23 37.7%	9 14.8%	17 27.9%	4 6.6%	**61** **100.0%**
28. Roofing activities	3 4.9%	4 6.6%	24 39.3%	10 16.4%	16 26.2%	4 6.6%	**61** **100.0%**

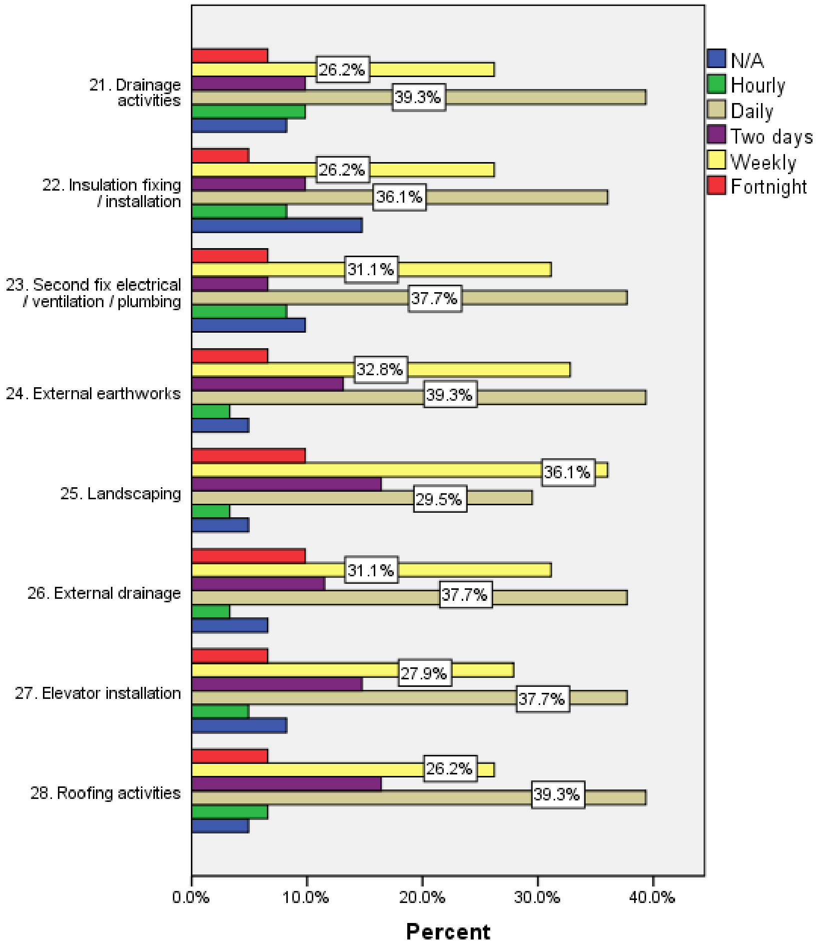

Figure 5.24: Percent transpose bar for Q23 (21-24) and Q24 (25-28)

The record in Figure 5.24 shows that Landscaping Weekly is 36.1% higher than Daily is 29.5%.

Table 5.26: Q1 plus frequency and percent for total Q19-24 in the cross tabulation

Total Q19 – Q24		**Total Q19-24 (61 respondents times 28 example tasks = 1708)**						**Total**
		N/A	**Hourly**	**Daily**	**Two days**	**Weekly**	**Fortnight**	
Q1	Execution role: General	0	0	28	0	0	0	**28**
		0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	**100.0%**
	Management role: CEO	0	3	70	17	50	0	**140**
		0.0%	2.1%	50.0%	12.1%	35.7%	0.0%	**100.0%**
	Project Manager	0	8	75	46	36	3	**168**
		0.0%	4.8%	44.6%	27.4%	21.4%	1.8%	**100.0%**
	Building Surveyor	0	1	24	0	3	0	**28**
		0.0%	3.6%	85.7%	0.0%	10.7%	0.0%	**100.0%**
	Main Contractor / Suppliers	0	0	0	6	22	0	**28**
		0.0%	0.0%	0.0%	21.4%	78.6%	0.0%	**100.0%**
	Software Programmer	0	45	39	0	0	0	**84**
		0.0%	53.6%	46.4%	0.0%	0.0%	0.0%	**100.0%**
	Planner	0	2	28	7	35	12	**84**
		0.0%	2.4%	33.3%	8.3%	41.7%	14.3%	**100.0%**
	Architect / Lead designer	56	11	16	19	46	20	**168**
		33.3%	6.5%	9.5%	11.3%	27.4%	11.9%	**100.0%**
	Information Manager	6	0	21	12	73	0	**112**
		5.4%	0.0%	18.8%	10.7%	65.2%	0.0%	**100.0%**
	BIM Manager / BIM Co-ordinator	54	33	304	39	130	56	**616**
		8.8%	5.4%	49.4%	6.3%	21.1%	9.1%	**100.0%**
	Cost consultant / quantity surveyor	0	0	15	9	4	0	**28**
		0.0%	0.0%	53.6%	32.1%	14.3%	0.0%	**100.0%**
	Civil Engineer	0	0	18	6	4	0	**28**
		0.0%	0.0%	64.3%	21.4%	14.3%	0.0%	**100.0%**
	Other	1	6	113	41	35	0	**196**
		0.5%	3.1%	57.7%	20.9%	17.9%	0.0%	**100.0%**
Total		**117**	**109**	**751**	**202**	**438**	**91**	**1708**
		6.9%	**6.4%**	**44.0%**	**11.8%**	**25.6%**	**5.3%**	**100.0%**

The total example tasks of data majority of respondents (44%) prefer that model should show changes on daily bases.

Table 5.27: Total results between Q11b and Q16g (Yes & Sometimes)

Q1a: Occupation Role – (Frequency)	Q11b: If yes in what way was 4D BIM used in projects? - Yes								Q16g: Yes	Q16g: Sometimes
	Communicating the plan to client	As part of the project planning phase	Communicating between contractors / subcontractors	Site logistics or space planning	Site safety briefings	Toolbox talks	Work package conflict detection	Other		
Execution role: General – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	100% (1)	0% (0)
Management role: CEO – (5)	60% (3)	60% (3)	60% (3)	60% (3)	40% (2)	40% (2)	40% (2)	0% (0)	20% (1)	60% (3)
Project Manager – (6)	33.3% (2)	50% (3)	33.3% (2)	33.3% (2)	16.7% (1)	0% (0)	33.3% (2)	0% (0)	16.7% (1)	50% (3)
Building Surveyor – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	100% (1)	0% (0)
Main Contractor / Suppliers – (1)	100% (1)	100% (1)	100% (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	100% (1)
Software Programmer – (3)	66.7% (2)	100% (3)	66.7% (2)	66.7% (2)	66.7% (2)	33.3% (1)	66.7% (2)	0% (0)	100% (3)	0% (1)
Planner – (3)	33.3% (1)	33.3% (1)	33.3% (1)	33.3% (1)	33.3% (1)	0% (0)	0% (0)	0% (0)	100% (3)	0% (1)
Architect / Lead designer – (6)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	50% (3)	33.3% (2)
Information Manager – (4)	75% (3)	50% (2)	50% (2)	75% (3)	25% (1)	0% (0)	25% (1)	25% (1)	25% (1)	75% (3)
BIM Manager / BIM Co-ordinator – (22)	72.7% (16)	72.7% (16)	45.5% (10)	59.1% (13)	18.2% (4)	18.2% (4)	22.7% (5)	22.7% (5)	18.2% (4)	68.2% (15)
Cost consultant / quantity surveyor – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	100% (1)
Civil Engineer – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	100% (1)	0% (0)
Other – (7)	85.7% (6)	71.4% (5)	71.4% (5)	71.4% (5)	71.4% (0)	14.3% (1)	57.1% (4)	42.9% (3)	42.9% (3)	57.1% (4)

Table 5.28: Pearson's correlation between Q11b and Q16g (Yes & Sometimes)

Correlations

		Q11b: Communicating the plan to client	Q11b: As part of the project planning phase	Q11b: Communicating between contractors or subcontractors	Q11b: Site logistics or space planning	Q11b: Site safety briefings	Q11b: Toolbox talks	Q11b: Work package conflict detection	Q11b: Other
Q16g - Yes	Pearson Correlation	-.453	-.350	-.407	-.178	.082	-.056	-.095	-.257
	Sig. (2-tailed)	.120	.241	.167	.560	.790	.855	.757	.397
	N	13	13	13	13	13	13	13	13
Q16g - Sometimes	Pearson Correlation	.495	.357	.443	.156	-.077	.005	.046	.320
	Sig. (2-tailed)	.085	.231	.129	.610	.802	.987	.882	.286
	N	13	13	13	13	13	13	13	13

The Pearson's Correlation of Q16g –Yes in Table 5.28 have problem details below:

- Moderate (negative) downhill (r= -.178) relation exists with respondents which used 4D BIM for "Site logistics or space planning" as they do not think that would be more beneficial for subdividing the model. While weak downhill (negative) linear relationship (r= -.095) is related to respondents which used 4D BIM for "Work package conflict detection" because they would be less interested to keep works.
- In addition, the respondents who said that 4D BIM was used predominantly for "Communicating the plan to client" they responded less interested in subdividing the model. Correlation value (r= -.453) is in range of weak downhill linear relationship.
- In conclusion, the majority respondents have identified value in changing the levels of detail (LOD) of 4D Model what is shown in a strong correlation of usage 4D BIM for "Site safety briefings" (r= +.082).

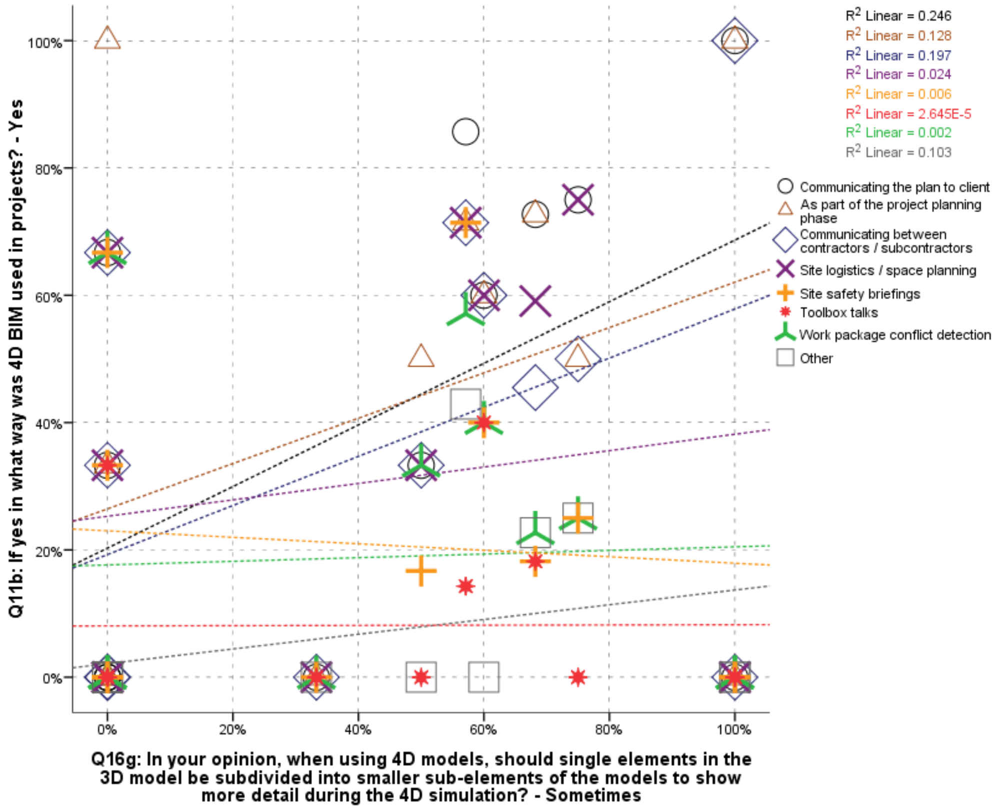

Figure 5.25: Established linear Q11b vs Q16g (Sometimes)

Cross reference was carried out between how 4D BIM was used for a project and in comparison, with the question of the ability to subdivide the model (e.g. Q11b vs Q16g – Sometimes). The result of the scatterplot graph in Figure 5.25 as well as the correlation values indicates the combination of a strong, moderate and weak uphill (positive) linear relationship.

Table 5.29: Total results between Q11b and Q1a

Q1a: Occupation Role – (Frequency)	Q1a:Percent	Q11b: If yes in what way was 4D BIM used in projects? - Yes							
		Communicating the plan to client	As part of the project planning phase	Communicating between contractors / subcontractors	Site logistics or space planning	Site safety briefings	Toolbox talks	Work package conflict detection	Other
Execution role: General – (1)	1.6%	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Management role: CEO – (5)	8.2%	60% (3)	60% (3)	60% (3)	60% (3)	40% (2)	40% (2)	40% (2)	0% (0)
Project Manager – (6)	9.8%	33.3% (2)	50% (3)	33.3% (2)	33.3% (2)	16.7% (1)	0% (0)	33.3% (2)	0% (0)
Building Surveyor – (1)	1.6%	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Main Contractor / Suppliers – (1)	1.6%	100% (1)	100% (1)	100% (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Software Programmer – (3)	4.9%	66.7% (2)	100% (3)	66.7% (2)	66.7% (2)	66.7% (2)	33.3% (1)	66.7% (2)	0% (0)
Planner – (3)	4.9%	33.3% (1)	33.3% (1)	33.3% (1)	33.3% (1)	33.3% (1)	0% (0)	0% (0)	0% (0)
Architect / Lead designer – (6)	9.8%	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Information Manager – (4)	6.6%	75% (3)	50% (2)	50% (2)	75% (3)	25% (1)	0% (0)	25% (1)	25% (1)
BIM Manager / BIM Co-ordinator – (22)	36.1%	72.7% (16)	72.7% (16)	45.5% (10)	59.1% (13)	18.2% (4)	18.2% (4)	22.7% (5)	22.7% (5)
Cost consultant / quantity surveyor – (1)	1.6%	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Civil Engineer – (1)	1.6%	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Other – (7)	11.5%	85.7% (6)	71.4% (5)	71.4% (5)	71.4% (5)	71.4% (0)	14.3% (1)	57.1% (4)	42.9% (3)

Table 5.30: Pearson's correlation between Q11b and Q1a

Correlations

		Q11b: Communicating the plan to client	Q11b: As part of the project planning phase	Q11b: Communicating between contractors or subcontractors	Q11b: Site logistics or space planning	Q11b: Site safety briefings	Q11b: Toolbox talks	Q11b: Work package conflict detection	Q11b: Other
Q1a Occupation role	Pearson Correlation	.363	.336	.194	.477	.191	.319	.277	.502
	Sig. (2-tailed)	.223	.261	.525	.099	.533	.288	.359	.080
	N	13	13	13	13	13	13	13	13

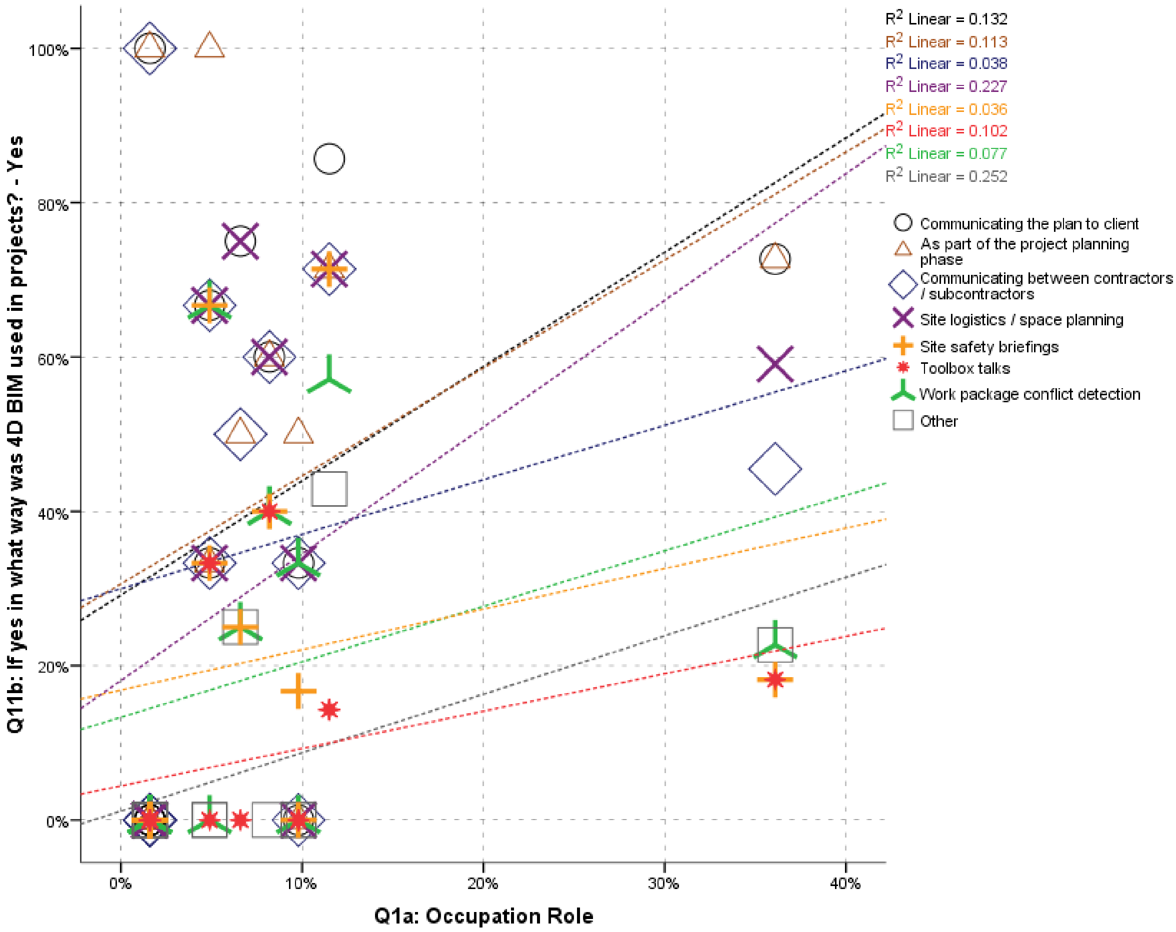

Figure 5.26: Established linear Q11b vs Q1a

Cross reference was carried out between Q11b and Q1a. There is a strong correlation between using 4D BIM for "Communicating the plan to client" Pearson's Correlation (r= +.363), for "As part of the project planning" (r= +.336) and BIM Managers / BIM Co-ordinators while the strong correlation was presented between software programmer and using 4D BIM for "Site safety briefings" (r= +.191), "Working package conflicts detection" (r= +.277) and "Site logistic or space planning" (r= +.477). The result given explains that software programmers perceive these levels of detail as valid and presenting that is more consistent than e.g. BIM Managers / BIM Co-ordinators.

Table 5.31: Total results between Q11b and Total Q19-Q24

Q1a: Occupation Role – (Frequency)	Q11b: If yes in what way was 4D BIM used in projects? - Yes								Total Q19-Q24 Daily	Total Q19-Q24 Weekly
	Communicating the plan to client	As part of the project planning phase	Communicating between contractors / subcontractors	Site logistics or space planning	Site safety briefings	Toolbox talks	Work package conflict detection	Other		
Execution role: General – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	100% (28)	0% (0)
Management role: CEO – (5)	60% (3)	60% (3)	60% (3)	60% (3)	40% (2)	40% (2)	40% (2)	0% (0)	50% (70)	35.7% (50)
Project Manager – (6)	33.3% (2)	50% (3)	33.3% (2)	33.3% (2)	16.7% (1)	0% (0)	33.3% (2)	0% (0)	44.6% (75)	21.4% (36)
Building Surveyor – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	85.7% (24)	10.7% (3)
Main Contractor / Suppliers – (1)	100% (1)	100% (1)	100% (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	78.6% (22)
Software Programmer – (3)	66.7% (2)	100% (3)	66.7% (2)	66.7% (2)	66.7% (2)	33.3% (1)	66.7% (2)	0% (0)	46.4% (39)	0% (0)
Planner – (3)	33.3% (1)	33.3% (1)	33.3% (1)	33.3% (1)	33.3% (1)	0% (0)	0% (0)	0% (0)	33.3%(28)	41.7% (35)
Architect / Lead designer – (6)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	9.5% (16)	27.4% (27)
Information Manager – (4)	75% (3)	50% (2)	50% (2)	75% (3)	25% (1)	0% (0)	25% (1)	25% (1)	18.8% (21)	65.2% (73)
BIM Manager / BIM Co-ordinator – (22)	72.7% (16)	72.7% (16)	45.5% (10)	59.1% (13)	18.2% (4)	18.2% (4)	22.7% (5)	22.7% (5)	49.4% (304)	21.1% (130)
Cost consultant / quantity surveyor – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	53.6% (15)	14.3% (4)
Civil Engineer – (1)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	64.3% (18)	14.3% (4)
Other – (7)	85.7% (6)	71.4% (5)	71.4% (5)	71.4% (5)	71.4% (0)	14.3% (1)	57.1% (4)	42.9% (3)	57.7% (113)	17.9% (35)

Table 5.32: Pearson's correlation between Q11b and Q19-Q24 (Daily & Weekly)

Correlations

		Q11b: Communicating the plan to client	Q11b: As part of the project planning phase	Q11b: Communicating between contractors or subcontractors	Q11b: Site logistics or space planning	Q11b: Site safety briefings	Q11b: Toolbox talks	Q11b: Work package conflict detection	Q11b: Other
Total Q19-Q24 - Daily	Pearson Correlation	-.489	-.442	-.505	-.156	-.042	.059	-.010	-.044
	Sig. (2-tailed)	.090	.131	.078	.610	.891	.849	.973	.886
	N	13	13	13	13	13	13	13	13
Total Q19-Q24 - Weekly	Pearson Correlation	.558	.380	.555	.108	-.112	-.193	-.190	.114
	Sig. (2-tailed)	.047	.200	.049	.725	.717	.527	.534	.711
	N	13	13	13	13	13	13	13	13

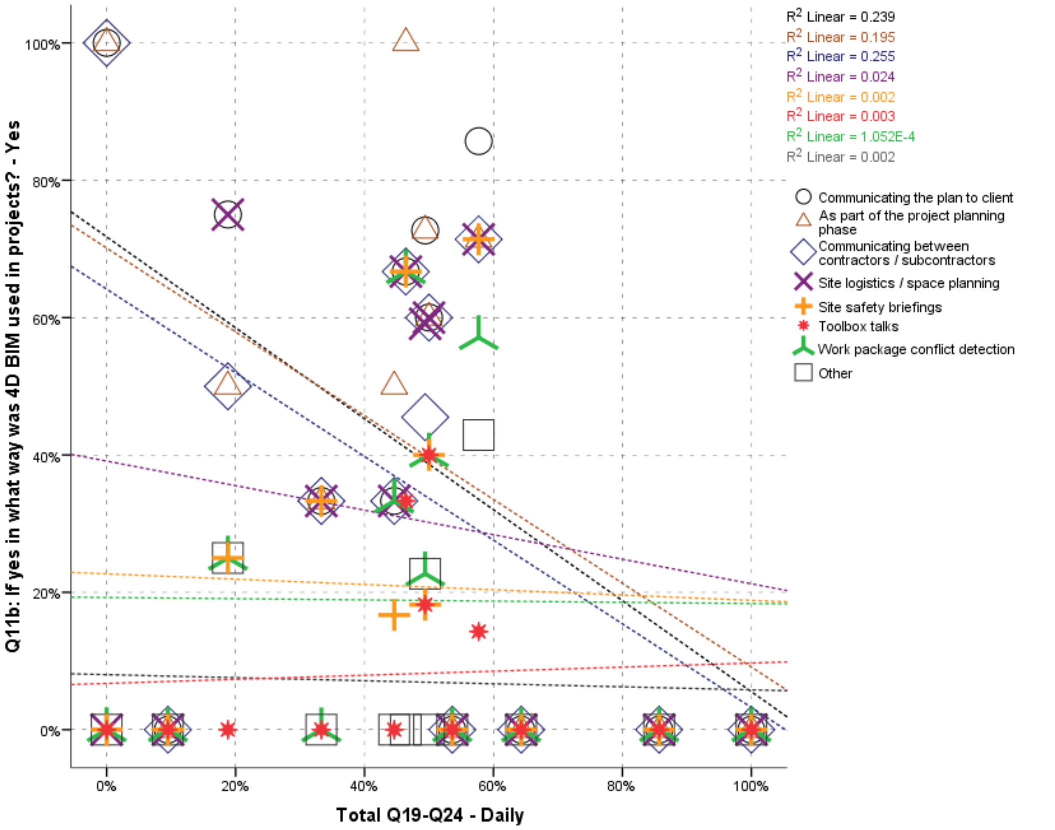

Figure 5.27: Established linear Q11b vs Total Q19-Q24 - Daily

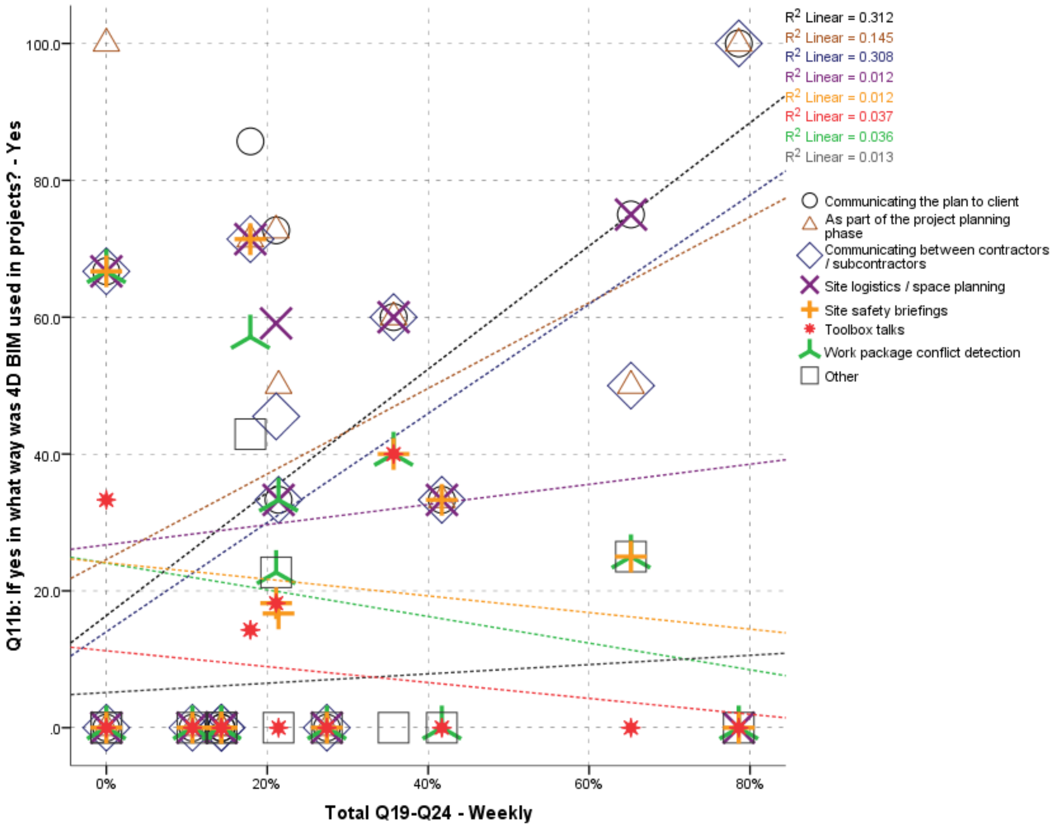

Figure 5.28: Established linear Q11b vs Total Q19-Q24 - Weekly

Cross reference was carried out between Q11b and Q19 – Q24.There is a negative correlation Pearson’s correlation (r= -.156) for daily between “Site logistic or space planning” and daily model should be positive to change the model meaning respondents would not have known how to update the model every day, two days and hourly but this is different to even strong correlations was identified between “Site logistic / space planning” in Pearson’s correlation (r= +.108) for weekly meaning they would update the model a long week. In conclusion, this confirms that system needs to be updated every day.

5.1.2 Responder profile

The first stage of the survey analysis was conducted using descriptive methods to gain a level of understanding of the demographic of the responders and the range of work they currently undertake (Figure 5.29). The highest number of responders fell into the category of BIM Manager/Coordinator/Information Manager (42.6%; n=26), followed by Project Management / Planning (27.9%; n=17), Lead Designer/Engineer (14.8%; n=9), Other management (11.5%; n=7) and Surveyor (3.3%; n=2) in **Appendix E: Grouped Occupation Role**.

The majority of those responding to the survey had worked in the industry for over 15 years, with the median working time having been between 4 and 10 years. The BIM Manager/Coordinator/Information Manager roles showed the highest number of years worked in the sector with most having experience of between 10-15 years. It could be inferred from this that those in the BIM roles have moved into those roles from other specialisms as BIM has become more widespread.

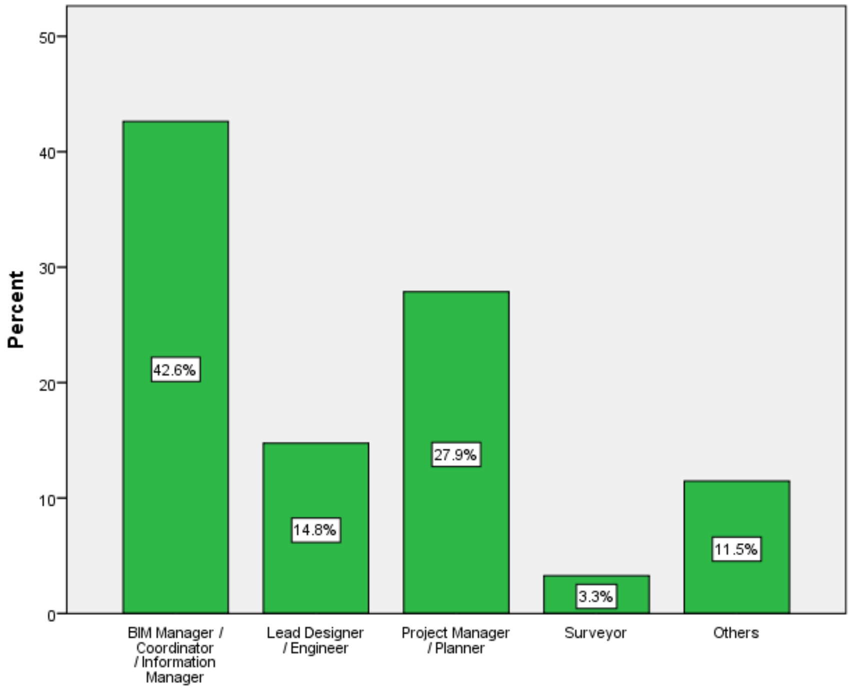

Figure 5.29: Demographic role of respondents

(Source: Butkovic *et al*., 2019)

The majority of the respondents to the survey were currently working in the commercial construction sector (59%), followed by civil/infrastructure (34%) and residential (7%). Furthermore, the results demonstrate that the responses came from an even cross section of SME and larger companies with 34% also coming from 'small companies' comprised of 50 people or less. Within the cross section of responders 92% had engaged in projects where BIM had been used. 75% of these identified the experience they had as being at the UK BIM Level 2 standard and the majority (66%) had been working at this level for between 3-5 years. On the issue of software, the results mirrored those reported annually in the NBS BIM Survey (NBS, 2018), which highlighted Autodesk Revit and Graphisoft ArchiCAD as those most used on BIM based construction projects. However, information was also garnered around the use of 4D simulation tools with Autodesk Navisworks proving the most popular, followed by Synchro and finally Bentley ConstructSim.

5.1.3 4D modelling issues

The second phase of the questionnaire sought to develop further understanding of the experience of participants with respect to 4D usage and also elicit knowledge around the perception of how 4D simulations are developed to show the more dynamic nature of the construction process. In terms of more 'traditional' 1D (time based) project planning, a range of software applications were used with the most popular being Microsoft Project, followed by Primavera, Powerproject and then others which included which included tools such as Microsoft Excel. Of the responses received, it was shown that 62.3% had made use of 4D BIM on construction projects and where it had been used, it had been predominantly applied for purposes of communication with either the client or between contractors and sub-contractors. Other uses included logistics or to enhance the actual planning phase to support development of what-if scenarios during the planning stages (Figure 5.30). The results broadly concur with those found by Gledson and Greenwood (2016) who found similar uses for 4D which can thus provide a level of credence to the cross section sample within this study.

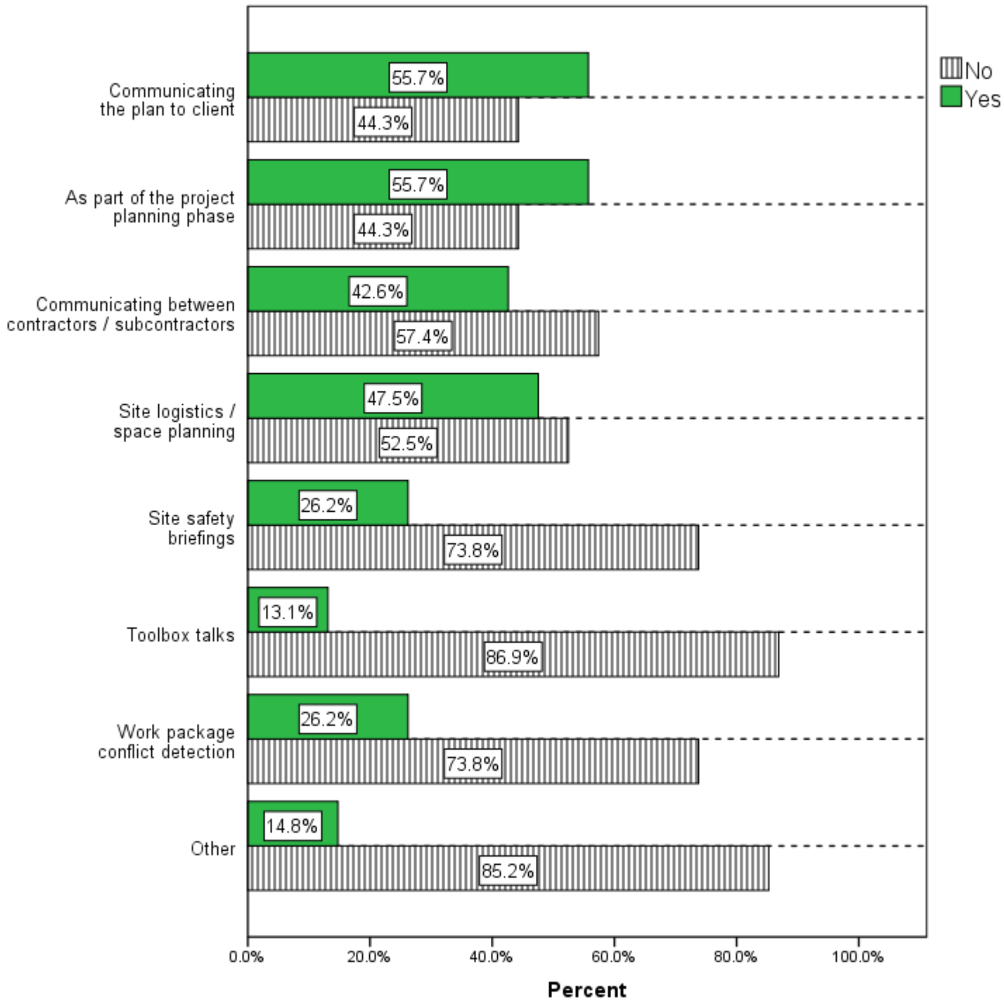

Figure 5.30: 4D BIM usage in construction projects

(Source: Butkovic *et al*., 2019)

In order to further investigate this aspect of 4D development, a correlation analysis (Figure 5.31) was undertaken using Pearson coefficient between the usage of 4D BIM and those responding. This demonstrated there is a strong correlation between using 4D BIM for "Communicating the plan to client" (r= +.534), and BIM Managers / Co-ordinators / Information Managers while a strong correlation was presented between Project Managers / Planners and using 4D BIM for "Working package conflicts detection" (r= +.208) and "Site logistic or space planning" (r= +.549) (Table 5.34). The result could impact on the LOD_{4d} and some of the discussions noted in the previous section whereby it potentially points to the BIM Managers/Coordinators would be involved in the development of lower LOD_{4d} whereas the Project Managers would be involved in higher LOD_{4d}. This could be as expected, however it does have potential to require the project managers to engage in software tools for the development of high LOD_{4d} simulations using decomposition techniques etc.

Table 5.33: Total results between Q11b and Q1a

		Q11b: If yes in what way was 4D BIM used in projects? - Yes							
Q1a: Occupation Role – (Frequency)	**Q1a: Percent**	**Communicating the plan to client**	**As part of the project planning phase**	**Communicating between contractors / subcontractors**	**Site logistics or space planning**	**Site safety briefings**	**Toolbox talks**	**Work package conflict detection**	**Other**
BIM Manager / Coordinator / Information Manager	42.6%	73.1%	69.2%	46.2%	61.5%	19.2%	15.4%	23.1%	23.1%
Lead Designer / Engineer	14.8%	11.1%	11.1%	11.1%	0%	0%	0%	0%	0%
Project Manager / Planner	27.8%	47.1%	58.8%	47.1%	47.1%	35.3%	17.6%	35.3%	0%
Surveyor	3.3%	0%	0%	0%	0%	0%	0%	0%	0%
Others	11.5%	85.7%	71.4%	71.4%	71.4%	71.4%	14.3%	57.1%	42.9%

Table 5.34: Pearson's correlation between Q11b and Q1a

Correlations

		Q11b: Communicating the plan to client	Q11b: As part of the project planning phase	Q11b: Communicating between contractors or subcontractors	Q11b: Site logistics or space planning	Q11b: Site safety briefings	Q11b: Toolbox talks	Q11b: Work package conflict detection	Q11b: Other
Q1a Occupation role	Pearson Correlation	.534	.649	.416	.549	.056	.677	.208	.132
	Sig. (2-tailed)	.354	.236	.486	.338	.929	.209	.737	.833
	N	5	5	5	5	5	5	5	5

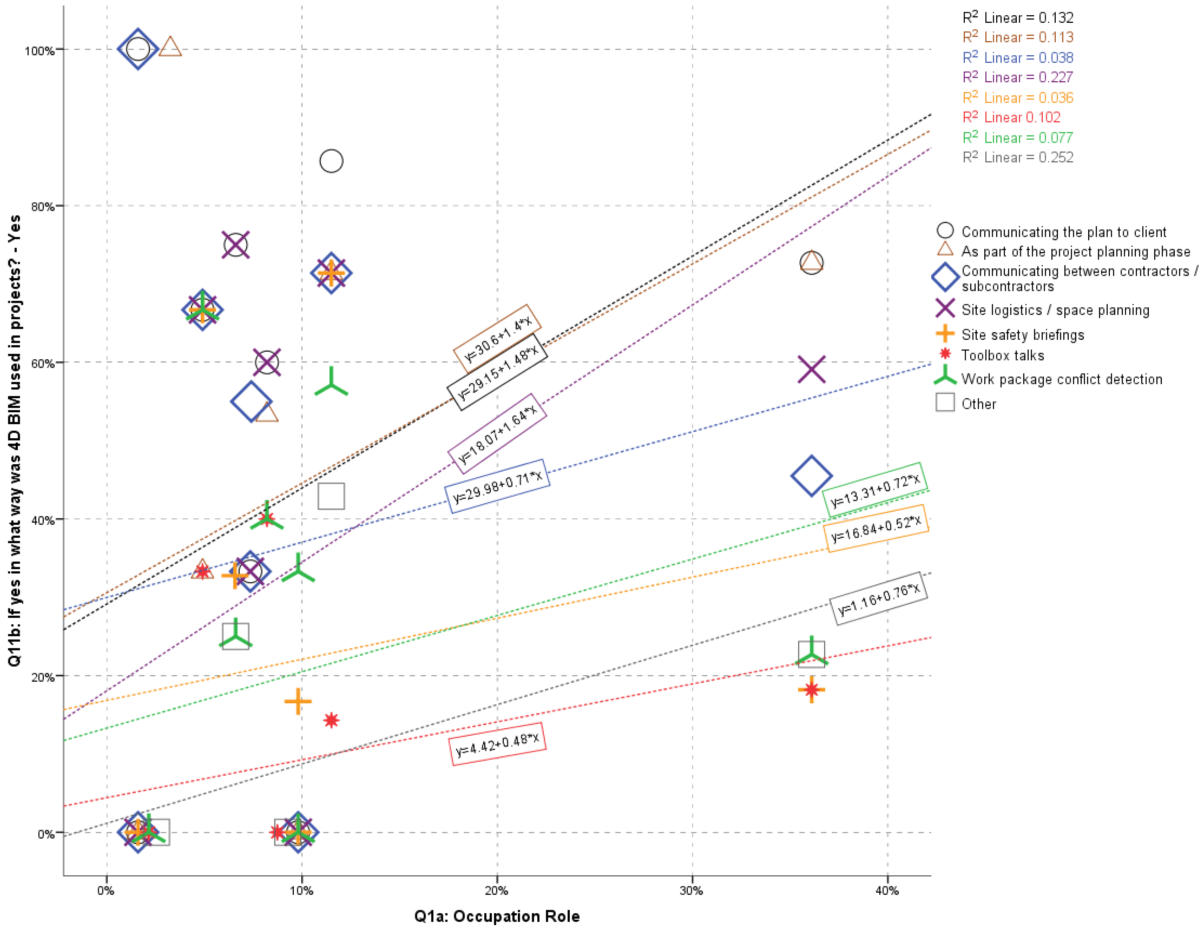

Figure 5.31: Established linear Q11b vs Q1a

As 4D BIM becomes more prominent in construction projects, the responsibility for development of the 4D simulation is also now becoming more fluid. During initial research in the early 21st Century, it was postulated that the construction planner would undertake the development of the 4D simulation and the associated software would become part of the planners' toolbox (North *et al.*, 2003a). However, as part of this study it was initially hypothesised that as BIM is becoming a specialism and is developing new roles within the industry, so the development and creation of the 4D simulation is falling under the remit of the 'BIM Coordinator / Manager'. The responses to the questionnaire demonstrate that 70% of 4D simulations were actually generated by either BIM (or CAD) technicians or BIM Coordinators / Managers or BIM/4D specialists. 30% were developed by Project Managers or Project Planners. Whilst this still leaves a level of ambiguity, as the initial project schedule of activities were developed by project planners, the development of the 4D and the linking of tasks / sequences to 3D geometric objects was still left to others. Somewhat contradicting this, 68% of responders were of the opinion that the generation of the 4D simulation should be the role of the project manager or project planner. This dichotomy of 4D BIM responsibility is something that requires further in depth consideration outside of the scope of this study but could be attributed to lack of knowledge of current 4D software tools or inability to use current software packages or the lack of direct integration between traditional temporal based planning tools and the 3D technologies associated with the BIM process. With respect to any future LOD_{4d} it could be questioned if the BIM coordinator/manager has the expertise and knowledge of the construction process to develop the 4D model. If not then input would still be required from the planner and/or construction manager to specify the LOD_{4d} from which the simulation could be developed.

Current 4D BIM software technology provides the ability to vary the LOD_{ti} i.e. the time horizon between state changes in the simulation. This can be set to specific intervals within all of the software tools noted in the previous section of the paper. Additionally, several of the existing software tools now provide the ability to either group individual objects or subdivide the geometry of 3D model within the 4D environment to provide the user / planner to develop a more detailed 4D simulation (for example sub-dividing a complete slab generated as 1 geometric object in the BIM authoring tool into subsections for the purpose of planning). This ability to subdivide the geometry to provide greater detail and granularity of the 4D model is critical and 95% of the questionnaire responders agreed that the ability to undertake this provides the ability to produce a more realistic and useful 4D simulation.

However, it still remains an issue to have a single 4D simulation that has the potential to move between various LOD_{ti} as the simulation evolves without having to stop the process and re-specify the time between state changes. 61% believed that the ability to change the LOD within the 4D model was beneficial and could provide more flexibility to the end use of the simulation. The time between state changes varies for various tasks on various projects and is also a subjective factor depending on several variables such as the end use of the 4D model. In order to further understand this phenomenon, the questionnaire asked those who had previously used 4D simulations what LOD_{ti} had been applied. 41% noted that 1-week had been used as the value, 21% stated 1 month had been used, 21% had changed the 4D model on a daily or bi-daily basis and 7% had used the simulation to show changes on an hourly basis. One responder (BIM Manager, #17 ID Participant in **Appendix E: Responses**) noted that *'…hourly is very common for management and proof of method in advance works'* and another noting that this sometimes changes to facilitate *'…live re-planning'* during a project. Specifically in the area of logistics planning and the use of 4D to alleviate clashes between trades and time space planning during the project, 91% stated that a higher level of graphical detail in the model (LOD_g) and a shorter time period between state changes in the 4D model (LOD_{ti}) were used to undertake a more ‘micro’ level of 4D. Interestingly it was predominantly the project managers / planners who specified time between state changes for the simulation (58%).

5.1.4 Example temporal LOD (LOD_{ti})

The responses highlighted above demonstrated that a significant number of the professionals identify the potential benefits of having varying LOD_{ti} within a 4D simulation with nearly two-thirds noting that often it is beneficial to have multiple graphical LOD (LOD_g) and multiple time based on LOD (LOD_{ti}) on a project. This could be particularly true for large projects where some elements may require more detailed planning to enhance issues such as site logistics. In order to gain further insight into this aspect, the third phase of the questionnaire provided a list of 28 nominal construction tasks, which could be represented in a 4D simulation and asked, the responders to note what they believed the optimum temporal stage change would be for each task. The level of graphical detail of the geometric objects was removed from this element so as to understand purely the variance in LOD_{ti} required. From here this could then be used to inform how geometric objects may need to be subdivided.

Figure 5.32 notes that predominantly responders sought the example tasks to be visualized in the 4D simulation on a daily basis aligning with the results discussed above. Whilst this was the most frequent response for all of the nominal tasks, there was also appetite for tasks to be viewed using a range of LOD_{ti}. The majority was either daily or weekly, however there were some instances activities such as piling, formwork and ductwork installation had higher instances of those believing that hourly changes would be beneficial to see. These activities are deemed to be highly dynamic in nature and are also often the cause of time space conflicts during the construction process (Kang *et al.*, 2012; Wu and Chiu, 2010).

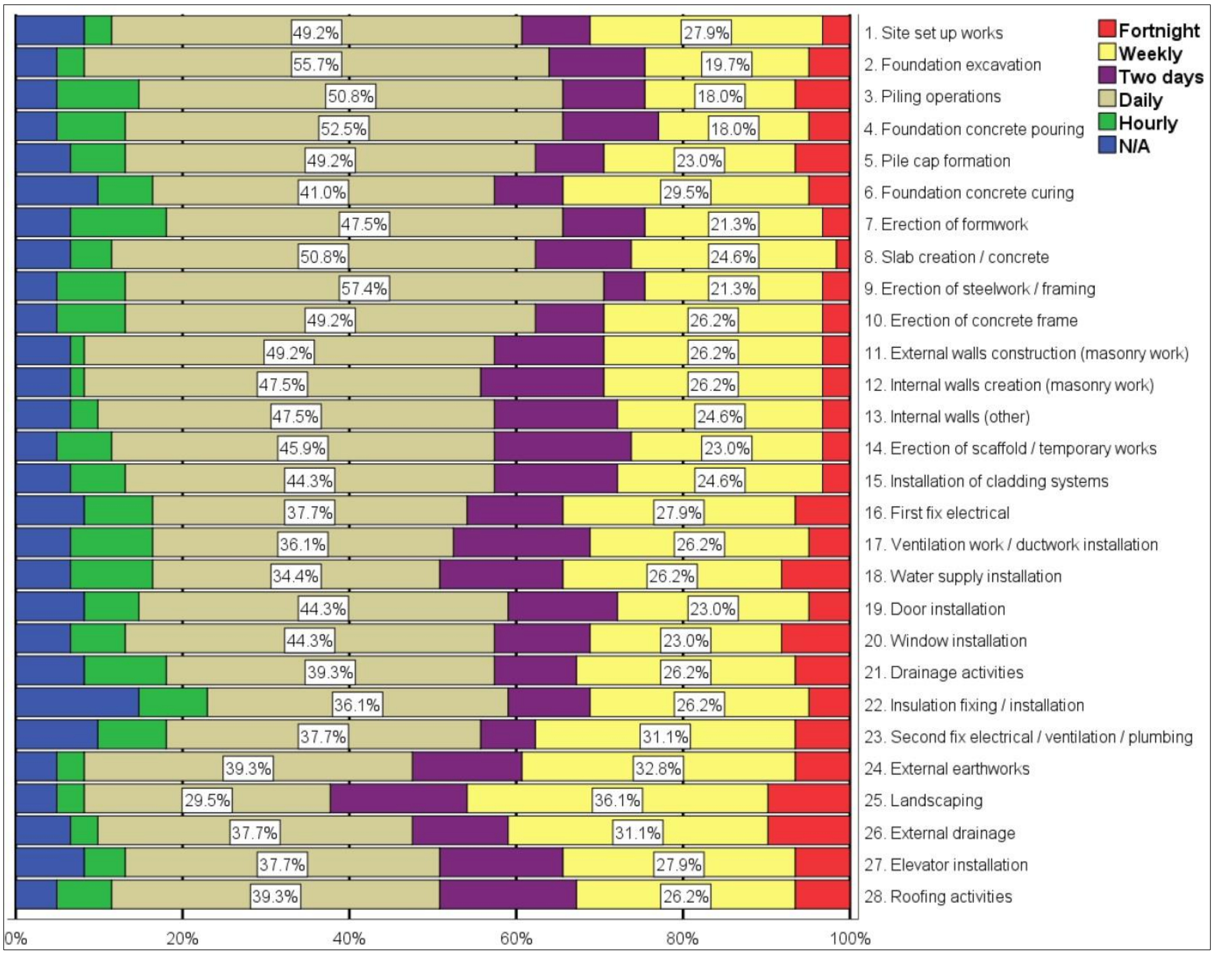

Figure 5.32: LOD_{ti} in 4D simulations for nominal construction tasks

(Source: Butkovic *et al*., 2019)

Cross referencing these results against the roles of the responders demonstrates that the BIM coordinators generally prefer to view the progress in the 4D simulation on a daily basis and this is mirrored by the project planners and project managers, with some exceptions and anomalies noted above. However, the lead designers lean more towards seeing progress on a weekly basis. This also correlates to the potential use that each of these particular groups sees as the potential main use of the 4D simulation. With planners and mangers seeing the use of the simulation to support construction work and the designers seeing benefits of the simulation as a more communication tool, particularly for clients.

5.2 Summary

The data received from the questionnaire survey was comprised of a range of professionals who were categorised into those whose specialism was BIM, those who were designers, project planner/management and surveyors. This gave a cross section of those who currently utilise 4D BIM for a range of applications. It is becoming clear from the results of this survey that the development of 4D models is falling under the remit of the BIM specialists more than the construction planner. This itself is worthy of note as from the early days of 4D development, it was hailed as a tool to support construction planning and specifically the construction planner. In order to produce a 4D simulation that contains the appropriate level of detail input would be needed from the construction planner and the construction management team to specify the LOD_{ti} and, if the geometry is to be divided or grouped to give a more realistic simulation, then a construction strategy/methodology would be required to support updates to the 3D geometry. It may be possible in the future to automate some of these processes with the advances in AI and build upon some of the early work on construction strategies and zoning.

The ability to generate more 'realistic' simulations of the construction process is controlled by the ability to a) view realistic graphical representations of individual objects during construction and b) better control the time between state changes of the 4D model (LOD_{ti}) which then has an impact on how individual geometric objects from the BIM are subdivided. The graphical LOD of the BIM objects in the design model will play a part in governing the representation of single objects in the 4D simulation. However, some previous work has identified that for the purposes of site logistics planning and management, a low LOD of geometric objects is adequate (North *et al.*, 2003b). The overwhelming response from the questionnaire noted that the ability to subdivide the geometry to show a more granular level of progress in the 4D simulation was beneficial. Linking this to a schedule with a higher level of detail will then provide a more detailed 4D simulation which, from the results, planners see as beneficial during logistics planning of site operations.

Some work has previously noted that the current use of 4D is actually a visualization tool to review the already developed construction plan rather than a tool used within the planning process (Zhou *et al.*, 2009c) and these results may corroborate this theory but further work is needed in this regard. The range of software tools to support the development of 4D is still limited, primarily down to the very specific nature of the task and the uses of 4D at the present time are still very much focused on the communication to various stakeholders in the construction process. This is still a significant benefit, however it appears that the opportunity to move beyond this usage into the application for detailed briefing, site logistics management and interactive project planning is yet to be realised and as this moves forward it will become necessary to specify the LOD of the 4D simulation in the same way that the LOD and LOI are specified for models in the BIM process.

Chapter 6: Framework Development and Validation

6.1 Introduction

The chapter put forward a final framework enhancing the components needed for improving a 4D BIM simulation. This chapter discuss achieved framework validation purpose, scope, general description and discussion. Once the survey data analysis was completed the researcher had enough data to develop the framework for specifying the LOD of 4D simulation (LOD_{4d}). The step forward was to present the framework to the targeted industry practitioners in regard to validate the components and processes.

The developed conceptual framework was designed on literature findings and the questionnaire analyses provided information for improving the framework design for LOD of 4D simulation. However, it was considered crucial to verify if the requirements identified are accurate and inclusive. The group of the industry specialists was chosen to validate the framework requirement.

6.2 Framework Development

It is based on the survey results and building on the initial conceptual framework that the wider remit of this work proposes to create a new methodology for the specification of the LOD of 4D simulations (Figure 6.1). The overall 4D LOD (LOD_{4d}) is a unification of Level of Graphical Detail (LOD_{g}) and the Level of Temporal Detail (LOD_{ti}) which details the time required in the simulation between state changes.

However, the graphical LOD should be a combination of the detail of the geometry representing the final product (i.e. the BIM LOD) and the Level of Detail of granularity (LOD_{gran}), which depicts how the object should be decomposed during the linking process.

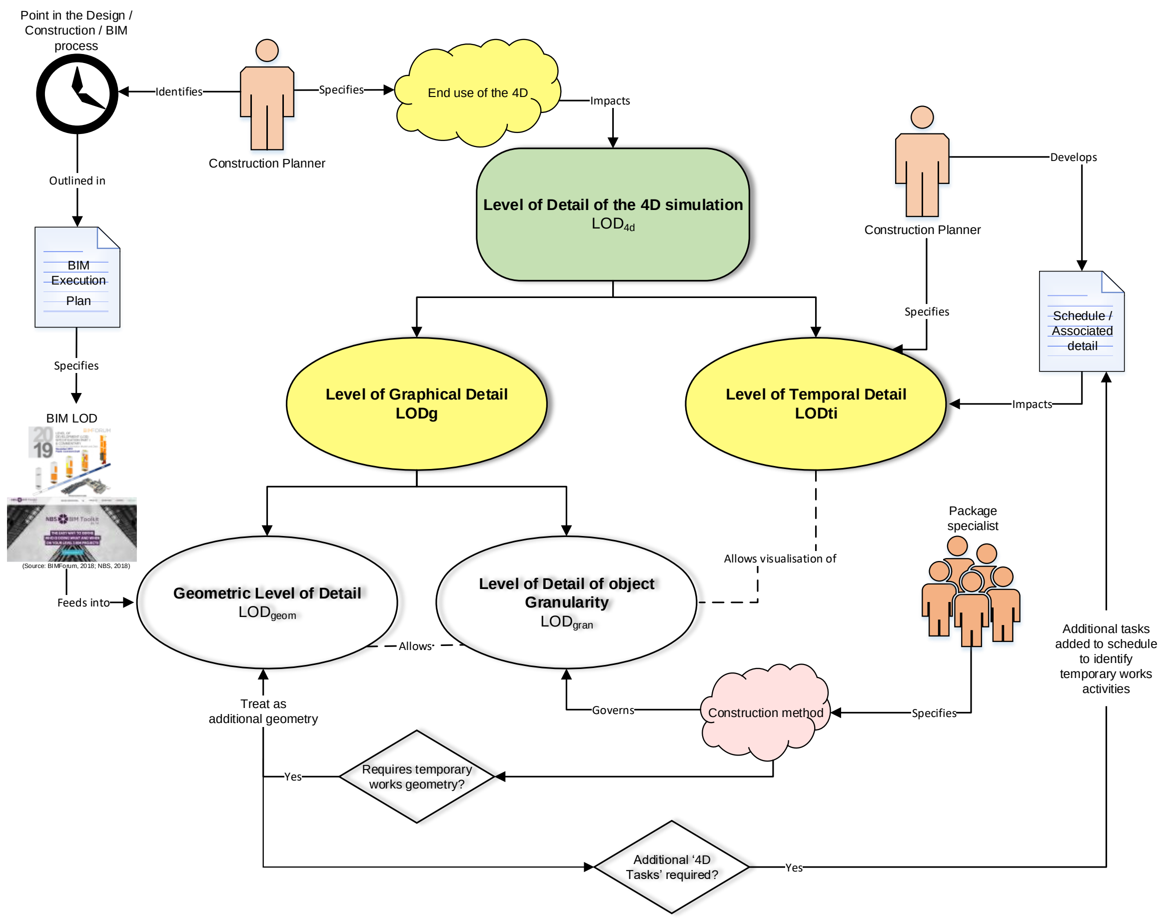

Figure 6.1: Framework for specifying the LOD of a 4D simulation (LOD_{4d})

(Source: Butkovic *et al.*, 2018)

It is also noted that temporary works are also now becoming a key factor in the use of 4D for more effective construction planning. Whilst Cassano and Trani (2017) discuss the level of geometric detail of temporary works elements when included in a BIM authoring tool, work such Kim and Cho (2015) or Cheng and Chang (2018) detail how temporary structures or temporary laydown areas can be included in the 4D simulation to provide a more robust and realistic view of the construction simulation.

Furthermore, several of the commercial 4D tools available, such as Navisworks and Synchro, provide the ability to animate objects within the 4D simulation and this is being used to highlight route paths of plant or turning envelopes of cranes. Very often, this serves as a more aesthetic purpose to provide a level of graphical 'realism' to the simulation, however it is noted that in Autodesk Navisworks the ability exists to detect clashes between animated objects in a 4D environment. The results of the survey undertaken in this study do highlight there is more limited appetite for the use of state changes and LOD_{ti} on an hourly basis which may be most suited to the animation of plant objects. However, this is something that could be included as part of the granularity LOD_{gran} aspect of the LOD_{g} specification and as such the framework highlights the issue of temporary works and how this is fed into the 4D simulation.

Often these construction/erection and deconstruction of objects associated with temporary works are additional to the BIM geometry and so also need to be considered. This will require specifying the geometric detail of any objects and also the granularity of the geometry as it is being constructed - for example the erection of scaffolding over several days. The inclusion of temporary works may also require the addition of tasks into the schedule to facilitate the development of 4D objects.

By providing the ability to begin to specify the LOD of a 4D simulation, the potential now exists to configure the simulation for a specific purpose. In much the same way as the BIM process can now begin to specify the LOD and LOI tailored to the use of the model and the data required by the client, so the 4D simulation can be tailored to suit the project and / or specific work packages within the project. This will remove the 'one size fits all' approach of many 4D simulations at the moment and move to support the notion reported above from questionnaire responses, which highlighted the benefit of being able to change the LOD within the 4D model during the process.

Whilst this approach does provide a theoretical underpinning to undertake this, there are still technological developments to be made to software tools to allow this to happen. The ability to move between LOD_{ti} and LOD_{gran} within a 4D simulation is required to be seamless. At the present this would have to be undertaken by stopping and reconfiguring the simulation for a certain period.

The framework identified 4D primary factors which impact the development of a dynamic LOD_{4d} simulations. The *End Use* of the simulation will impact the LOD_{4d} and this can be reflected by the stage of the project and the user of the simulation. For example, early concept stage simulations would potentially require less detail and may be shown as part of the planning approval. Later stage simulations may be used by the contracting team and require more detail. The *Temporal LOD* encompasses the temporal stage change of the simulation and the breakdown/detail of the construction schedule.

The amount of detail in the construction schedule can impact this directly. Whilst the construction schedule is generally developed by the construction planner at various stages of the project, there are examples of work, such as Faghihi *et al*. (2014) which investigates the application of automated generation of schedules and this is something that could impact the LOD_{ti} development of 4D in the future. The *Graphical LOD* will encompass the amount of detail contained within the geometry of the BIM aligning to prevailing standards such as the AIA LOD in the USA and the NBS LOD approaches in the UK.

The geometric breakdown of the product breakdown structure for a 4D simulation is based on how the elements are decomposed and the strategy used to do this. This is often a factor of the construction approach adopted by the planner. Generally this is undertaken manually either within the 4D tool, or as part of the BIM creation in the authoring software, however there have been examples of approaches (Heesom, 2006d) where this is undertaken using a more automated approach. The *Linking Mechanism* relates to the existing technology solutions which provide the ability to link the graphical data and schedule information.

6.2.1 Recommendation for Framework application

Whilst 4D is often seen as a tool for the main contractor and to manage site activities, it also needs buy in from the sub-contractors to ensure that the graphical and temporal information is available to meet the needs. The effective development of a 4D model encompasses the geometric models of the designers, main contractors and the specialist sub-contractors. In addition, the schedule for each of the work packages is required at a relevant level of detail. It is for this reason that it proposed that the issue of 4D data requirements for each stage of the project is included as part of the BIM execution plan for the project.

In alignment with PAS1192-2 (BSI, 2013b) the BEP highlights the data structure and requirement for each stage of the project and this can now include issues around LOD_{4d}. To ensure the correct data is available, an addendum to the BEP specifically focused on 4D requirements is proposed as future work, based on the outcomes of this study. This will provide a LOD_{4d} matrix, similar to the Model Production Delivery Table (MPDT) utilised in the UK BIM Level 2 standards.

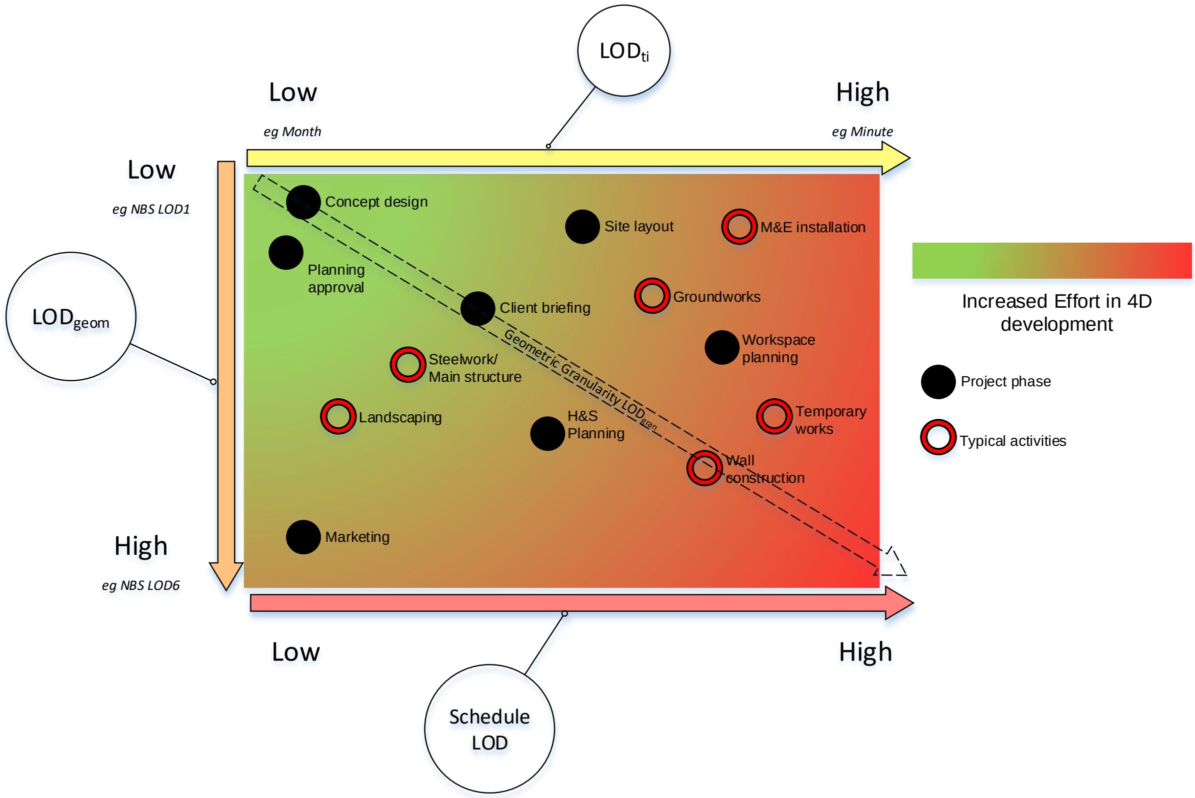

Figure 6.2: LOD_{4d} schematic and use cases

(Source: Butkovic *et al.*, 2019)

Building on this, the findings from literature and the results of the questionnaire a LOD_{4d} schematic is proposed to provide guidance on how each of the constituent LOD factors link and inform some example use cases (Figure 6.2). There are a range of factors that can influence the level of detail including the schedule detail, the time between state changes and the detail of the geometry which can then be granulated.

Results show that 4D is currently used significantly for client briefings and marketing often this will require a low level of temporal detail with some high graphic content to 'sell' the scheme. As a further example, where 4D is used for workspace planning and logistics a highly detailed schedule can be used, linked with a detailed BIM model which can then be subdivided further and visualized using a high level of temporal detailed.

6.3 Purpose of Validation

According to Creswell and Plano Clark (2007) a significant point of a good research is clear clarification on validity and reliability of data and results. During this research the data collection and data analysis validity and reliability of the results were considered. As the conceptual framework for dynamic 4D model was created based on literature review the survey results provided strong points for updating the initial framework. Thus the reliability seen in the preliminary framework components and the credible survey results initiated the development of the framework for specifying the LOD of a 4D simulation (LOD_{4d}).

The framework validly confirms the credibility and the strengths of a research study. In order to undertake the qualitative framework validation, the participants needed to be presented with information gathered (Soler, 2006).

6.4 Scope of Validation

The validation protocol is defined as the experimental plan that designs carefully the validation program. A written plan should contain enough detail and background and it needs to describe the "what" the "why" and the "how" the validation will be done (IVT Network, 2017).

The data collected through the survey was gathered from one structured questionnaire, and the quality of the results provided by the data analyses is of ultimate importance for the research. The chosen group for the framework validation based on the results, were required to contribute with their assessment if the framework fit for their companies' purposes.

The researcher started with the sending emails to potential participants in order to spur their involvement in validation process. First email enclosed a short explanation of the survey analyses and critical results. If the chosen expert agrees to take part in validation stage the expert would be introduced with developed frameworks and all justifications for the framework design.

The next step was to agree on the interview where in live conversation the participant gave the opinion of the framework, possible implementation, and the idea of the framework improvements in **Appendix G**.

6.5 General Description

For the ethical reasons the identities of the participants who engaged in framework validation are protected but the job titles of the same are identified. The industry practitioners involved in the validation project were: Virtual Design and Construction (VCD) specialists, Information BIM Mangers, Project Manager and Senior Consultant. The industry practitioners were targeted in the regard of working and being aware of the all aspects of the 4D BIM technology. Therefore, the responders are working in both the public and private sectors, they belong to different age groups and they are from India, Australia, the US and the UK.

Six semi-structured interviews were conducted with actors involved in the framework validation in the period of one month, depending on their availability. All interviews were performed over Skype or LinkedIn and each interview lasted approximately 45 minutes. The respondents agreed overall that the framework in general is valid and applicable to all construction projects where BIM is mandated.

For this study purposive or judgmental sampling was chosen which is a strategy in where particular backgrounds individuals are selected intentionally in order to deliver important information that cannot be acquired from other choices (Maxwell, 1996).

A sampling body was chosen purposively as the selected individuals needed to be expertise in order to focus and highlight the prospective of the framework. As there was a lack of both theoretical and practical evidence, in this area, before this research commence, the opinion of the specialists was needed to justify if the innovation properties are worthy for the industry practices. In addition, the purposive sampling was chosen for this study with determination to include the diversity at some international level of the participants and bring broader optimistic vibe for the framework (Patton, 1990, 2002; Kuzel, 1999).

6.6 Discussion

One month has been selected in order to validate the designed framework and collect anticipated options and suggestions from the industry specialists in order to further improve the framework.

In this project some questions have been asked in order to trace the direction from practitioner' behaviour during the project's lifecycle and the awareness on the subject. The reason for doing the validation interviews could be seen in the importance of showing that efficiency of some standards and classification systems in theory could be used in the real world. Framework validation interviews were done with industry actors as an aim to evidence the need of those who would use the framework in order to ensure effective task completion.

The interviews were taken as transcripts which gives possibility of proper analysis even though the transcribing process is often time-consuming.

Live chat interviews allowed industry experts to give their insights on issues in a more private setting, enabling the researcher to obtain answers and ideas. One-to-one interviews assisted more up close and personal idea, based on the experience of the interviewees themselves. Interviews verified to be a valuable instrument in bringing together different viewpoints on the subject that helped to confine and clarify some concerns raised during the previous phases of the study.

The table below portraits the reflections of the framework design in the participants' experiences and their current practices.

Table 6.1: Analyses of the framework validation interviews

(Source: updated from Butkovic *et al.*, 2018)

Questions	**Responses**	**Key findings from the validation (common themes)**	**Relation with the framework**
Do you think that the framework as presented accurately addresses the needs of your company?	• *To a large extent yes.* **(VDC Specialist, #1 ID Participant in India)** • *Yes. It takes into account the 4D inputs necessary to design a suitable process.* **(Information Manager, #2 ID Participant in the UK)** • *I think it is a good start, however perhaps more consideration could be given to how the 4D programme will be developed with other project deliverables and design development.* **(Project Manager, #3 ID Participant in Australia)** • *Actually, for a good number of our clients, this is all they need but we get a biased sample as the companies that hire our services are pretty advanced in the practice.* **(Senior Consultant, #4 ID Participant in the US)** • *I would say "yes", but I would like to make certain distinction. As software vendor, we are provider of BIM technology, not the receiver.* **(Product Manager, #5 ID Participant in the UK)**	Majority of respondents confirms that presented framework can address accurately the needs of companies where they work.	This encourages the author in effort to endure and address potential improvements.
If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?	• *The level of effort to implement the framework would be minimal. The level of effort to implement the information within the framework would vary depending on my clients. And would vary from much effort to a great level of effort.* **(Information Manager, #2 ID Participant in the UK)** • *This is a great question, but I'm not sure it applies what my company does is two things mainly sell software and sell consulting services.* **(Senior Consultant, #4 ID Participant in the US)** • *Very little effort, as many of the framework concepts, already exist and are established implemented (where they are implemented).* **(Product Manager, #5 ID Participant in the UK)** • *Well that's a difficult question because it is a framework not a specification - if you are saying all this will be set as mandatory and international or national standards will set the effort / granularity, then it could be quite involved.* **(BIM Manager, #6 ID Participant in the UK)**	If the AEC industry were to implement the framework as designed, they would require minimal effort to do so on all BIM mandated projects but would also depend of the Client needs.	This encourages the author in effort to endure and address potential improvements.

Where do you think the level of detail in the 4D simulation should be specified?	• *In the EIR* (Employers Information Requirements) **(Information Manager, #2 ID Participant in the UK)** • *In the BIM Execution Plan and maybe at high level in the EIR* **(Project Manager, #3 ID Participant in Australia)** • *In Contract Specs or BIM execution plan.* **(Senior Consultant, #4 ID Participant in the US)** • *into the design/engineering* **(Product Manager, #5 ID Participant in the UK)** • *In an Employers Information Requirements for a BIM project.* **(BIM Manager, #6 ID Participant in the UK)**	In EIR (Employers Information Requirements) & in BIM Execution Plan	Framework should adopt the common theme.
How relevant do you think this approach would be to a typical construction project?	• *Very relevant* **(Information Manager, #2 ID Participant in the UK)** • *It is not relevant to a 'Typical' construction project....yet. Here in Australia BIM is becoming more frequently used however the adoption of 4D planning is minimal.* **(Project Manager, #3 ID Participant in Australia)** • *Very relevant* **(Senior Consultant, #4 ID Participant in the US)** • *The framework will be relevant for ANY project using BIM, some industries will see larger relevance (and benefit) - for example, buildings, single location projects.* **(Product Manager, #5 ID Participant in the UK)** • *Very relevant assuming the project had a reasonable complexity.* **(BIM Manager, #6 ID Participant in the UK)**	Relevance of the framework approach in construction projects was confirmed by all interview participants.	Framework should adopt the common theme.
How might you use that framework on a construction project where you need 4D?	• *We are almost following the same framework. We do design the 4D in the same lines.* **(VDC Specialist, #1 ID Participant in India)** • *To help ensure the 4D requirements are considered.* **(Information Manager, #2 ID Participant in the UK)** • *I think your framework is a very good method of helping a team de-mystify how 4D should fit in to the bigger picture BIM delivery. I think it would have to be further refined on a 'case-by-case' basis depending on the particular project requirements.* **(Project Manager, #3 ID Participant in Australia)** • *You use the point in construction that is mentioned in your framework to determine the LOD combination that gives highest ROI (return of Investment) then you follow the rest of the framework.* **(Senior Consultant, #4 ID Participant in US)** • *I would use it to change the methods of planning and scheduling and specify the requirement for 4D more clearly, to gain measurable benefits.* **(Product Manager, #5 ID Participant in the UK)** • *I would expect a supplier to provide a process map for managing inputs and outputs for 4D, in specifying 4D in EIRs you could look at sources of information and confirm responsibilities and roles in 4D modelling.* **(BIM Manager, #6 ID Participant in the UK)**	The framework suggested could be used on 4D construction projects to change the methods of planning and scheduling by specifying 4D requirements clearer and processing inputs and outputs in EIRs and verify responsibilities and roles in 4D modelling. However, it needs to be refined on a case-by-case base and related to specific project requirements.	Framework should adopt the common theme.
How might you improve the framework?	• *By putting comparability between the software.* **(VDC Specialist, #1 ID Participant in India)** • *Consider CBS (cost breakdown structure) and risk* **(Information Manager, #2 ID Participant in the UK)** • *An LOD can be referenced for model LOD; however, I have not yet seen a document that outlines 4D schedule LOD. This could be a very good idea. Potential some form of high-level guidance of what would be expected for various levels of detail in the schedule would be good to support the framework.* **(Project Manager, #3 ID Participant in Australia)** • *You split LOD into graphical and time, where is really should be Model and time, and then model should be split to geometry detail, parameters/data, and functional visualizations (crane reach, caution area, etc.).* **(Senior Consultant, #4 ID Participant in the US)** • *I think showing it as an input - process - output model - SIPOC analysis and showing the level of maturity in projects against it and defining if the client or supplier is responsible for the input source. Adding logistic pathways and cost level of information to the graphical may help clarify the inputs better.* **(BIM Manager, #6 ID Participant in the UK)**	Potential needs to include CBS (cost breakdown structure) and high-level guideline to address various LODs in a 4D schedule.	Framework should adopt the common theme.

According to interviews, the framework takes in account the 4D imputes necessary to design the suitable process. In their opinion the level of effort to implement the framework would be insignificant in all BIM mandated projects, as many of the framework concepts already exist, and they all agree that the necessary components are included. However, for the companies who are not BIM ready or at lower levels of implementation the effort would be significantly larger, this is due to the fact that the AEC industry is not BIM matured evenly. This could be seen in the main survey of the study where the question of the time interval of the changes in the simulation in respondents' answers in total has only 6.4% for the hourly scheduling and 44% for the daily scheduling. However, 87.2% of respondents agree that if a 4D model shows more details it can improve the identification of potential conflicts and clashes and they should have ability to change the details of the 4D directly within the software. If the progress of UK BIM Level 2 is based on the maturity of BIM Level 1, and BIM Level 2 the main requirement is to progressively capturing and enunciating information to support the whole lifecycle management of assets (McPartland, 2014), therefore hourly sequencing need more attention from industry practitioners in order to resolve issue regarding the absence of appropriate LOD.

6.7 Summary

This chapter has provided validation details of the framework for more dynamic 4D simulations. The creation of a such a framework was stated as the aim of this research. This work has presented a conceptual framework and built on the research survey and the validation of the theoretical framework a Framework for specifying the LOD of a 4D simulation (LOD_{4d}) was generated. The research indicates that the framework as created could be beneficial to the industry since the framework addresses the current industry needs to a high degree.

Chapter 7: Conclusions and Recommendations

7.1 Introduction

This final chapter summarises the complete review of the thesis and the work undertaken. The research study was set out to explore the impact of the level of detail in the 4D technology and the issues of communication and collaboration, in order to offer the most appropriate framework for more dynamic and more realistic 4D simulation. The research questions were answered by employing a mixed method strategy with a combination of online questionnaire and the live text interviews through Skype and LinkedIn social media.

All the pragmatic findings were considered within the particular chapters (Chapters: 4, 5, and 6) and allowed the researcher to gain an insight into professionals' experiences. Furthermore, the chapter highlights how the research objectives were addressed, limitation of the work, the contributions to knowledge made by this study, and the recommendation for the future work.

7.1.1 Research assessment

In this part, the objectives stated in Chapter 1 are looked over in contrast to the work completed. The evaluation of the objectives allows the valuation of whether the aim has been achieved. Five objectives were identified to assist the overall aim of developing the framework for specifying the 4D BIM LOD.

Table 7.1: Evaluation of the objectives specified for this study

Objective	Evaluation
Objective 1: Undertake a critical review of prevailing literature in the field of BIM and specifically the field of 4D modelling	To realise the task set in the first objective, a broad literature review was carried out to examine current and emerging industrial practices and research approaches surrounding BIM and 4D technology. The collaboration of all project participants at the very beginning of the construction project is critical, as well as throughout the all project stages. The literature introduces many case studies praising 4D technology for increasing communication through visualization. However, static image of a 4D model does not fully represent the dynamic construction project. The level of detail explanation which is used in the industry to classify the totality and the precision of the model does not include specific construction procedures.

Objective 2: Investigating prevailing 4D software tools used for schedule visualization in construction engineering, specifically the technical capabilities and LOD approaches.	To satisfy the criteria set out in the objective number 2 the investigation was carried out in order to identify technology for a 4D simulation. A range of software applications that support 4D modelling have come to the market. The core ability of these tools is the same, by which 3D components are linked with the temporal data through either linking on an individual or group base. In general, this is undertaken manually, however the functionality of these is evolving by allowing the link to be developed using automated algorithms using the attribute based data attached to 3D elements. With respect to the level of detail capabilities, all of the existing tools have the ability to change the time between state changes of the 4D simulations. However, it is not possible to have multiple temporal state changes within a single 4D simulation session.
Objective 3: To deeper explore issues around 4D use and the issue of Level of Detail within 4D in practice to bring out the knowledge.	This objective was satisfied by researching what is needed to produce the construction schedule and is the level of detail given in 4D modelling significant for 4D visualization. The construction schedule includes names of project activities their duration, relationship between activates and their classification. The schedule level of detail given in 4D modelling is insignificant for 4D visualization. The individual 3D elements within the 4D simulation allow project stakeholders to view what, where and often how construction process from design, procurement construction schedules. 4D technologies show the work of subcontractors, considerate traffic and site-flow processes. On site 4D models can be used for systematic construction advancement analyses. These models can be used to assess similarities and differences between as-built and as-planned schedules for management and evaluation purposes. Furthermore, 4D models can be used for reviewing progress and construction changes during the construction project which improves relationship between the client and construction team. There are also good results shown in renovation projects where 4D models are used to communicate the services and control system changes needed for the specific period during the renovation project.
Objective 4: Development of a framework for the implementation and application of LOD within 4D simulations	This objective was fulfilled by recognizing issues found in the literature where critical subjects were identified for improvement. According to literature analyses the improvement of 4D dynamics should be looked at construction planning, improvement of collective responsibilities as well as the level of detail in construction processes. 4D planning should increase

	communication among various parties involved in construction through adopting visualization for business needs, reduction in rework by having automated system of minimizing conflicts and provide better budget control as well as improving safety management on site. Conceptual framework was developed based on the above as well as on the fact of today's complex architectural models. The understanding of complex models could be aided by the technique of model decomposition that subdivides models into smaller significant sub-models. Once the anticipated framework was developed the research survey was conducted by using online questionnaire targeting industry participants. By collecting data of user evaluation, the goal was to reveal the potential usefulness of the proposed framework. The survey analyses provided results which initiated further development of the framework. Findings from literature and questionnaire results provided enough information, therefore the framework for specifying 4D BIM LOD was proposed.
Objective 5: Framework Validation	The effectiveness of proposed tools ought to be evaluated by construction professionals to satisfy the fifth and final objective. Six semi structured interviews were performed over Skype and LinkedIn. The responders agreed overall, that the framework in general is valid and applicable to all construction projects where BIM is mandated. Furthermore, all the interviewees agree that the framework takes in account the 4D imputes necessary to design the suitable process as many of the necessary components are included. Most evaluators felt that if 4D shows more details it can improve the identification of potential conflicts. This result was the same when the quantitative data was collected. As well as the opinion that the software solution would be the key to its uptake in this regard.

7.2 Limitation of work

All studies have limitations and the limitation of this project could be considered in few drawbacks:

- A number of the respondents of the survey was 101 questionnaires sent to potential participants and 61 was fully answered. The reason for this could be lack of familiarization on the subject. Although the participants were deliberately targeted some did not have a real input in the production of information. Even though the researcher informed parties with the current state of concerns and shed light on the subject, the completed questionnaires were two thirds of all sent. However, the sample size of analyses used in study gave a positive feedback for the research
- The study has identified limitation of the role for creating 4D simulation which should have been mainly responsibility of the Project Manager or Project Planner. However, the questionnaire responses demonstrate that 70% of 4D simulations were actually generated by either BIM (or CAD) technicians or BIM Coordinators / Managers.
- This study has not fully implemented the framework on a live construction project and so this would be needed to further elaborate on the framework and provide additional guidance on how the various elements of the framework could be implemented in a 4D simulation.

7.3 Contribution to knowledge

Although the work had limitations the project was finalized with an original framework. The project addresses the problem of communication among industry actors as the information coordination in the construction industry has become more important. There are different factors that influence the need for information coordination: the use of new technology, the enormous amount of data, the more complex models and the different types of data that need to be addressed.

There is also an increase in multidisciplinary work among parties involved in process and the need for re-use of information. All the aspects joined together consequently result in the need for information coordination and protocols for communicating information at a collective level of representation and understanding. Specifically, the main contributions of this study are:

7.3.1 Developed a full definition of the Level of Detail for 4D Simulations

Hitherto the issue of Level of Detail within 4D simulations has been discussed but the definition has not been fully defined. This study has developed a new approach to defining the LOD of a 4D simulation (LOD_{4d}). In developing this, it has proposed that the LOD_{4d} is multidimensional and comprises a graphical LOD of the initial model (LOD_g), the LOD of the granularity of objects decomposed or aggregated to form the 4D geometric objects (LOD_{gran}) and the Temporal LOD (LOD_{ti}) which specifies the time between state changes of the 4D simulation.

7.3.2 Definitive quantitative data to demonstrate the need for multi-LOD 4D simulations

The quantitative data collection chosen as one of the research strategy for the study, was the best way to answer the questions risen in this research. The greater number of participants (61) completed questionnaires and the quantitative research method allowed the researcher to target responders worldwide. The 83.6% of responders delivered confirmation that 4D simulations would be more accurate and the identification of potential clashes would be improved if 4D simulations show more details. In addition, for the total example task 44% out of 61 participants have a preference for the model to be changed on daily bases.

The good respond during the questionnaire time provided strong point for the development of the multi-LOD 4D simulation framework.

7.3.3 Development of a framework to highlight the dependencies and implementation of LOD_{4d} within a BIM based construction project

Therefore, the study was set to provide a framework for specifying 4D BIM LOD that can be developed and implemented. The study presents a framework for creating a more dynamic 4D model by using information from Building Information Modelling. The critical parts of the conceptual framework are the graphical level of detail and various levels of temporal detail. Both graphical and temporal levels of details are influenced by numerous factors crucial for the construction project.

Design teams should work at better coordination and effort to establish the model granularity of level of detail which would provide a more accurate 4D model. Literature review and research surveys provided creation of such a novelty which was positively validated and acclaimed by industry professionals.

The segments of this study have been published in related journals and presented at international conferences in **Appendix B**.

7.4 Recommendation for Future Research

This study presents the framework for specifying level of detail in 4D simulation which could improve the results in 4D model, providing more accurate and more realistic simulation. The proposed framework is a good method of helping a team de-mystifies how 4D should fit in the bigger picture of BIM delivery. As the idea of the outlining 4D schedule LOD in a document is a novelty, a good start would be referencing LOD of 4D to the various stages set out in PAS1192. Applying this framework into a 4D LOD in the field would deliver a more formal use of 4D simulation.

Future development could take the framework as a basis and further develop a 4D modelling protocol, which could sit alongside the BIM Execution Plan and support the construction activities using the BIM process.

Another concern for future work could be the software tool development. The study reveals all the 4D applications available on the market and none of the 4D software has the ability to change temporal steps. The simulation has multiple temporal steps and this technological obstacle needs to be resolved.

7.5 Recommendations for industry practice

When taking attention for the framework distribution and implementation, the industry need more liability in practitioners' knowledge and skills. Educating and improving workforce ought to be a main step in making an attempt to distribute the framework. The framework was developed with an aim to overcome the issues identified during the research. The survey analyses show that the employees in the construction sector have a little knowledge of who is responsible for 4D scheduling.

The interviewees who were engaged in validation stage confirmed that the industry has no form of high level guidance of what would be expected for various level of detail in the schedule to outline 4D LOD. As the responders were chosen worldwide and they confirmed the lack of such a document the framework would be accepted globally. Specific point should be given to project planers and BIM coordinators who are responsible for project controls. The construction planer has to specify and develop Level of Detail of the 4D simulation.

The starting point of the framework distribution and implementation ought to be seen in the document that states the uses of and requirements for BIM. The Employer's Information Requirements (EIR) set in UK PAS 1192-2:2013 clearly identify the project manager's responsibilities for coordination the information (Sawhney *et al.*, 2017).

This means that the specifying 4D LOD in EIR could be looked at sources of information and confirms responsibilities and roles in 4D modelling. The proposed framework provides the ability to begin to specify the LOD of a 4D simulation; thus, designers, contractors and clients need to improve collaboration through greater team integration.

All the details are indicated in the Employer's BIM Requirements regarding management:

- Standards,
- Roles and Responsibilities,
- Planning the Work and Data Segregation,
- Security coordination and Clash Detection Process,
- Collaborating Process,
- Health and Safety and Construction Design Management
- System Performance
- Compliance Plan
- Delivery Strategy for Asset Information

The above various BIM stages set out in PAS1192 should include LOD of 4D and thus provide a more formal use of 4D simulation. In order to implement proposed methodology, the whole anticipated terminology abbreviation must be recognized. This includes 4D LOD (LOD_{4d}), Level of Graphical Detail (LOD_g), Level of Temporal Detail (LOD_{ti}) and Level of Detail of granularity (LOD_{gran}) which represents how an object should be fragmented for the duration of the linking process.

The technical requirements for implementing the delivered framework for specifying 4D BIM LOD in PAS 1192 is crucial. Current software tools do not allow changes directly in the 4D simulation accordingly for implementing the proposed framework; the geometric breakdown structure would need manual work by the planners. However, the existing technology provides the connection of graphical data and schedule information which could be used for including the 4D BIM LOD in BIM requirements.

As supported by the PAS1192-6 2018 document (BSI, 2018), the use of 4D modelling will be seen as an essential part of digital technology practices for the construction industry. This Health and Safety PAS1192-6 2018 could initiate further development of the automated generation of schedules.

References

Abanda, F.H., Vidalakis, C., Oti, A.H. and Tah, J.H.M. (2015) A critical analysis of Building Information Modelling systems used in construction projects, *Advances in Engineering Software*, **90**, pp.183-201

Abrishami, S., Goulding, J., Rahimian., F.P. and Ganah, A. (2015) Virtual generative BIM workspace for maximising AEC conceptual design innovation, *Construction Innovation,* **15**(1), pp.24-41

Addison, A., O'Hare, W.T., Kassem, M. and Dawood, N. (2013) *The importance of engaging engineering and construction learners in virtual worlds and serious games* [online]. [Accessed 2 December 2015]. Available at <http://itc.scix.net/cgi-bin/works/Show?convr-2013-45>

Albert, L. (2014) *Project Management, planning and control: managing engineering, construction, and manufacturing projects to PMI, APM, and British standards.* 6th ed. Amsterdam: Butterworth-Heinemann

Akbas, R., Fischer, M., Kunz, J. and Schwegler, B. (2001) *CIB W78 Conference*, IT in Construction in Africa, Mpumalanga, South Africa, 29 May-1 June

Akbas, R., and Fischer, M. (2002) "Construction Zone Generation Mechanisms and Applications.", ISARC 2002, 19th International Symposium on Automation and Robotics in Construction, Sep. 23-25, 2002, Washington DC, USA, NIST SP 989, William C. Stone, editor, pp. 293-298

Anon (2015) BaboonLab. *WHAT IS BIM?* [online]. [Accessed 10 September 2015]. Available at: <http://www.baboonlab.com/bim.html>

Anon (2013) BIMTalk. *BIM Dimensions* [online]. [Accessed 10 September 2015]. Available at: <http://bimtalk.co.uk/bim_glossary:bim_dimensions>

Anon (2015) CODEBIM: Collaborative Design Education using BIM. *History of Building Information Modelling* [online]. [Accessed 15 July 2015]. Available at: <http://codebim.com/resources/history-of-building-information-modelling/>

Anon (2014) Impararia. *7D CAD OR HOW TO MANAGE ASSETS LIFE CYCLE – FACILITY MANAGEMENT* [online]. [Accessed 5 September 2015]. Available at: <http://www.impararia.com/en/services/bim/bim-7d>

Anon (2013) *Level of Development Specification – BIMForum PDF* [online]. [Accessed 7 November 2015]. Available at <http://bimforum.org/wp-content/uploads/2013/08/2013-LOD-Specification.pdf>

Anon (2011) Modern Building Services. *On the road to BIM* [online]. [Accessed 26 August 2015]. Available at: <http://www.modbs.co.uk/news/archivestory.php/aid/8765/On_the_road_to_BIM.html>

Anon (2013) Redbike Systems Pty Ltd. *Dimensions of BIM* [online]. [Accessed 27 August 2015]. Available at: <http://www.redbike.com.au/knowledge/dimensionsofbim.aspx>

Anon (2013) *Project Building Information Modeling Protocol Form Document G202 – AIA PDF* [online]. [Accessed 11 January 2016]. Available at <http://www.aia.org/aiaucmp/groups/aia/documents/pdf/aiab099086.pdf>

Anon (2013) *Standard Protocol for use in projects using Building Information Models – BIMProtocol PDF* [online]. [Accessed 11 January 2016]. Available at <cic.org.uk/download.php?f=the-bim-protocol.pdf>

Akinci, B., Fischer, M., Levitt, R., and Carlson, R. (2002). Formalization and Automation of Time-Space Conflict Analysis. *Journal of Computing in Civil Engineering*, 16(2), pp. 124-134.

Aouad, G., Lee, A., Wu, S. and Onyenobi, T. (2012) *Computer Aided Design Guide for Architecture, Engineering and Construction.* New York: Spon Press

Atkin, B. and Brooks, A. (2009) *Total Facilities Management*. 3rd ed. Oxford: Wiley-Blackwell.

Azhar, S. (2012) Building information modeling (BIM): now and beyond, *Australasian Journal of Construction Economic and Building*, **12**(4), pp. 15-28

Azhar, S., Hein, M. and Sketo, B. (2008) *Building Information Modeling (BIM): Benefits, Risks and Challenges – Auburn University PDF* [online]. [Accessed 30 August 2015]. Available at: <http://ascpro.ascweb.org/chair/paper/CPGT182002008.pdf>

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Calis, G. (2012) Application Areas and Data Requirements for BIM-Enabled Facilities Management, *Journal of Construction Engineering and Management*, **138**(3), pp. 431-442

Bedrick, J. (2013) *A Level of Development Specification for BIM Processes* [blog entry]. [Accessed 16 November 2015]. Available at: <http://www.aecbytes.com/>

Bernstein, H.M. (2010) *Green BIM – SmartMarket Report PDF* [online]. [Accessed 20 July 2015]. Available at: <http://www.wbdg.org/pdfs/mhc_smartmarket_rep2010.pdf>

Bhatia, M. (2018) *Your Guide to Qualitative and Quantitative Data Analysis Methods* [blog entry]. [Accessed 15 September 2019]. Available at: <https://humansofdata.atlan.com/>

Biljecki, F., Ledoux, H., Stoter, J. and Zhao, J. (2014) Formalisation of the level of detail in 3D city modelling, *Computers, Environment and Urban Systems*, **48**, pp.1-15

Borrmann, A., Ji, Y., Jubierre, R. and Flurl, M. (2012) *Procedural Modeling: A new approach to multi-scale design in infrastructure projects – Technische Universitat Mucnhen PDF* [online]. [Accessed 12 January 2016]. Available at: <https://www.cms.bgu.tum.de/en/>

Boton, C., Kubicki, S. and Halin, G. (2013) Designing adapted visualization for collaborative 4D applications, *Automation in Construction*, **36**, pp.152-167

Boton, C., Kubicki, S. and Halin, G. (2015***a***) The challenge of level of development in 4D/BIM simulation across AEC project lifecycle. A case study, *Procedia Engineering*, **123**, pp.59-67

Boton, C., Kubicki, S. and Halin, G. (2015***b***) 4D/BIM simulation for pre-construction and construction scheduling. Multiple levels of development within a single case study. *Creative Construction Conference 2015*, Krakow, Poland, 21-24 June, pp.500-505

Bryde, D., Broquetas, M. and Volm, J.M. (2013) The project benefits of Building Information Modelling (BIM). *International Journal of Project Management*, **31**, pp.971-980

BSI (British Standards Institute) (2013) *Specification for information management for the capital/delivery phase of construction projects using building information modelling* [online]. [Accessed 20 July 2018]. Available at <http://www.hfms.org.hu/web/images/stories/PAS/PAS1192-2-BIM.pdf >

BSI (British Standards Institute) (2018) *Specification for collaborative sharing and use of structured Health and Safety information using BIM* [online]. [Accessed 19 September 2019]. Available at <https://shop.bsigroup.com/>

Butkovic, B. and Heesom, D. (2017) Towards A Framework For Multi-LOD 4D BIM Simulations. *International Research Conference 2017*. University of Salford, 11-12 September, pp. 578-586

Butkovic, B., Heesom, D. and Oloke, D. (2018) The Framework Validation for Dynamic 4D BIM Simulations. *1st International Conference on Construction Future 2018 (ICCF2018)*. University of Wolverhampton, 19-20 December

Butkovic, B., Heesom, D. and Oloke, D. (2019) The need for multi-LOD 4D simulations in construction projects, ITcon Vol. 24, pp. 256-272, https://www.itcon.org/paper/2019/14

Cassano, M. and Trani, M.L. (2017) LOD standardization for construction site elements. *Procedia Engineering*, **196**, pp.1057-1064

Clark, J.H. (1976) Hierarchical Geometric Models for Visible Surface Algorithms, *Communication of the ACM*, **19**(10), pp.547-554

Cheng, M.Y. and Chang, N.W. (2018). Dynamic construction material layout planning optimization model by integrating 4D BIM. *Engineering with Computers*, pp.1-18

Creswell, J. W (1994) *Research Design: Qualitative and Quantitative Approaches*. Thousand Oaks. CA: Sage

Creswell, J. and Plano Clark, V. (2007) *Designing and Conducting Mixed Methods Research.* Thousand Oaks, CA: Saga

Choi, J., Choi, J. and Kim, I. (2014) Development of BIM-based evacuation regulation checking system for high-rise and complex buildings, *Automation in Construction*, **46**, pp.38-49

Chun, C.K. and Li, H. (2012) The use of virtual prototyping for hazard identification in the early design stage, *Construction Innovation*, **12**(1), pp. 29-42

Cuthill, M. (2002) Exploratory research: citizen participation, local government and sustainable development in Australia. *Sustainable Development*, **10**(2), pp.9-89

Dawood, N., Eknarin, E., Mallasi, Z. and Hobbs, B. (2002) Development of an integrated information resource base for 4D/VR construction processes simulation, *Automation in Construction,* **12**, pp.123-131

Dawood, N., Miller, G., Patacas, J. and Kassem, M. (2014) Construction health and safety training: the utilisation of 4D enabled serious games, ITcon Vol. 19, pp. 326-335, http://www.itcon.org/cgi-bin/works/Show?2014_19

Durcevic, S. (2019) *Your Modern Business Guide to Data Analysis Methods and Techniques* [blog entry]. [Accessed 15 September 2019]. Available at: <https://www.datapine.com/>

Eastman, C.M. (1999) *Building Product Models: Computer Environment Supporting Design and Construction.* Boca Raton: CRC Press

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011) *BIM Handbook – A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Constructors.* 2nd ed. New Jersey: Wiley

Faghihi, V., Reinschmidt, K.F. and Kang, J.H., (2014) Construction scheduling using genetic algorithm based on building information model. *Expert Systems with Applications*, **41**(16), pp.7565-7578.

Farooq, U. (2013) *Types of Research Design* [blog entry]. [Accessed 18 March 2019]. Available at: <http://www.studylecturenotes.com/>

Fischer, M. (2000) Benefits of 4D Models for Facility Owners and AEC Service Providers. *Construction Congress VI*, ASCE, Orlando, Florida, February 2000. Eds Walsh, K.D. pp.990-995

Fischer, M. and Kunz, J. (2004) *The Scope and Role of Information Technology in Construction – Stanford University PDF* [online]. [Accessed 25 June 2015]. Available at <http://cife.stanford.edu/sites/default/files/TR156.pdf>

Geyer, P. (2009) Component-oriented decomposition for multidisciplinary design optimization in building design, *Advanced Engineering Informatics*, **23**, pp.12-31

Gledson, B (2015) Investigating the diffusion of 4D BIM innovation In: Raidén, A B and AboagyeNimo, E (Eds) *Procs 31st Annual ARCOM Conference*, 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 641-650

Gledson, B. and Greenwood D.J. (2016) Surveying the extend and use of 4D BIM in the UK, ITcon Vol. 21, Special Issue Technology Strategies for Collaborative Working, pp. 57-71, https://www.itcon.org/paper/2016/4

Gledson, B. (2017) *Innovation Diffusion Within The UK Construction Sector: A Study Of The Adaption of 4D BIM*. PhD Thesis, University of Northumbria, UK

Granholm, L. (2011) *BIM, IT in construction, history, present and future – Tekla PDF* [online]. [Accessed 20 August 2015]. Available at <http://www.cse.tkk.fi/fi/opinnot/T-110.6000/2011/luennot-files/BIM_Aalto.pdf>

Groger, G., Kolbe, T.H., Nagel, C. and Hafele, K.H. (2012) *OGC City Geography Markup Language (CityGML) Encoding Standard – Open Geospatial Consortium PDF* [online] [Accessed 12 January 2016]. Available at: <http://www.opengeospatial.org/>

Groger, G. and Plumer, L. (2012) CityGML – Interoperable semantic 3D city models, *ISPRS Journal of Photogrammetry and Remote Sensing*, **71**, pp.12-33

Grytting, I., Svalestuen, F., Lohne, J., Sommerseth, H., Augdal, S. and Lædre, O. (2017) Use of LoD decision plan in BIM-projects, *Procedia Engineering*, **196**, pp.407-414

Guevremont, M. and Hammad, A. (2018) Multi-LOD 4D Simulation in Phased Rehabilitation Projects. *Proceedings of the 17th International Conference on Computing in Civil and Building Engineering (ICCCBE)*, Tampere, Finland, pp.724-731

Halpin, D.W. and Senior, B.A. (2012) *Construction Management*. 4th ed. Danvers: Wiley

Hamada, H.M., Haron, A.T., Zahrizan, Z.Z. and Humada, A.M. (2017) Implementation of 4D/BIM in the Iraqi construction industry. *International Journal of Engineering Systems Modelling and Simulations (IJESMS)*, **9**(4)

Hammer, M. and Champy, J. (1993) *Reengineering the Corporation: A Manifesto for Business Revolution*. London: Nicholas Brealey

Han, K.K. and Golparvar-Fard, M. (2015) Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs, *Automation in Construction*, **53**, pp.44-57

Hardin, B. and McCool, D. (2015) *BIM and Construction Management* [online]. Indianapolis: Wiley. [Accessed 10 October 2015]. Available at: <https://www.dawsonera.com/>

Hartmann, T. (2011) 4D models to support safe planning of hospital renovations. *Proceedings of CIB W78 2011*, Sophia Antipolis, France, pp. 1–10

Heesom, D. and Mahdjoubi, L. (2003) A Dynamic VR System For Visualizing Construction Space Usage. ASCE Construction Research Congress, Winds of Change: Integration and Innovation of Construction. Eds Molenaar, K. and Chinowsky, P. Honolulu, Hawaii. March 19-21 2003. ISBN: 0-7844-0671-5

Heesom, D. and Mahdjoubi, L. (2004) Trends of 4D CAD Applications, *Journal of Construction Management and Economics*, **20**(2), pp.171-182

Heesom, D. (2004) *An Analytical System for Space Planning on Construction Sites*. PhD Thesis, University of Wolverhampton, UK

Heesom, D. (2006) Interactive Generation of 'Multi-Level of Detail' 4D CAD Simulation: 6th International Conference on Construction. *Application of Virtually Reality*, Orlando, Florida, August 2006

Hergunsel, M. F. (2011) *BENEFITS OF BUILDING INFORMATION MODELING FOR CONSTRUCTION MANAGERS AND BIM BASED SCHEDULING*, MSc Thesis, Worcester Polytechnic Institute.

Huang, T., Li, H., Guo, H., Chan, N., Kong, S. and Skitmore, M. (2009) Construction virtual prototyping: a survey of use. *Construction Innovation: Information, Process, Management*, **9**(4). pp. 434-448.

IVT Network (2017) *Establishing Good Documentation Practices for method validation – IVT Network PDF* [online]. [Accessed 11 November 2018]. Available at <http://www.ivtnetwork.com/sites/default/files/8th%20Annual%20Method%20Validation.pdf#page=29>

Jones, D. M. (2011) *3D Laser Scanning for Heritage – English Heritage PDF* [online]. [Accessed 15 August 2015]. Available at <http://www.english-heritage.org.uk/publications/3d-laser-scanning-heritage2/>

Laakso, M. and Kiviniemi, A. (2012) THE IFC STANDARD – A REVIEW OF HISTORY, DEVELOPMENT, AND STANDARDIZATION, ITcon Vol. 17, pp. 134-161, http://www.itcon.org/cgi-bin/works/Show?2012_9

Leinonen, V., Kankaanpaa, M., Luukkonen, M., Kansanen, M., Hanninen, O., Airaksinen, O., and Taimela, S. (2003) Lumbar paraspinal muscle function, perception of lumbar position, and postural control disc herniation-related back pain, *Spine*, **28**, pp.842-848

Leite, F., Akcamete, A., Akinci, B., Atasoy, G. and Kiziltas, S. (2011) Analysis of modelling effort and impact of different levels of detail in building information models, *Automation in Construction*, **20**, pp.601-609

Liu, Y. and Li, S. (2013) Research on Virtual Construction in the Construction Phase and Its 4D LOD Analysis, *International Conference on Construction and Real Estate Management 2013 (ICCREM 2013)*, pp.289-297

Luebke, D., Reddy, M., Cohen, J.D., Varshney, A., Watson, B. and Huebner, R. (2003) *Level of Detail for 3D Graphics*. San Francisco: Morgan Kaufmann

Kang, L., Pyeon, J., Moon, H., Kim, C. and Kang, M., (2012) Development of Improved 4D CAD System for Horizontal Works in Civil Engineering Projects. *Journal of Computing in Civil Engineering*, **27**(3), pp.212-230.

Kensek, K.M. (2014) *Building Information Modeling*. New York: Routledge

Kensek, K. and Kahn, W. (2013) Integration of Environmental Sensors with BIM*: BESS-SB13, Building Enclosure Sustainability Symposium Sustainable Buildings Conference 2013.* Advancing Toward Net Zero. Pomona, California, June 2013

Kim, C., Kim, H., Park, T. and Kim, M. (2011) Applicability of 4D CAD in Civil Engineering Construction: Case Study of a Cable-Stayed Bridge Project, *Journal of Computing in Civil Engineering*, **25**(1), pp.98-107

Kim, K.P., Ma, T., Baryah, A.S., Zhang, C. and Hui, K.M. (2016) Investigation of readiness for 4D and 5D BIM adoption in the Australian construction industry. *Management Review: An International Journal*, **11**(2), pp.43-64

Kim, K. and Cho, Y. (2015) BIM-based planning of temporary structures for construction safety. *In Computing in Civil Engineering*, pp. 436-444

Koo, B. and Fischer, M. (2000) Feasibility study of 4D CAD in commercial construction. *Journal of Construction Engineering and Management*, **126**(4), pp.251-260

Kreider, R.G and Messner, J.I. (2013) *The Uses of BIM – Classifying and Selecting BIM Uses – Penn State University PDF* [online]. [Accessed 11 January 2016]. Available at <http://bim.psu.edu/uses/the_uses_of_bim.pdf>

Kriphal, M. and Grilo, A. (2012) Compatibility between design and construction building information models, *ECPPM Proceedings*, pp.447-452

Krygiel, E., Nies, B. and McDowell, S. (2008) *Green BIM: successful sustainable design with building information modeling*, Indianapolis: Wiley Publishing.

Kuzel, A. J. (1999) *Sampling in qualitative inquiry*. In B. F. Crabtree & M. B. Miles (Eds.), *Doing qualitative research*. 2nd ed. Thousand Oaks: Sage

Madsen, J.J. (2008) *Build Smarter, Faster, and Cheaper with BIM* [blog entry]. [Accessed 30 August 2015]. Available at: <http://www.buildings.com/>

Mahalingam, A., Kashyap, R. and Mahajan, C. (2010) An evaluation of the applicability of 4D CAD on construction projects, *Automation in Construction* **19**(2) 148-159.

Maxwell, J. A. (1996) *Applied social research methods series, Vol. 41*. *Qualitative research design: An interactive approach*. Thousand Oaks, CA, US: Sage Publications, Inc.

McDonald, M.A., Lipscomb, H.J., Bondy, J. and Glazner, J. (2009) "Safety is everyone's job." The key to safety on a large university construction site, *Journal of Safety Research*, **40**, pp.53-61

McGeorge, D. and Zou, P. (2013) *Construction Management: New Directions.* 3rd ed. West Sussex: Wiley

McPartland, R. (2014) *BIM Levels explained* [blog entry]. [Accessed 2 November 2018]. Available at: <https://www.thenbs.com/>

Moon, H., Dawood, N. and Kang, L. (2014) Development of workspace conflict visualization system using 4D object of work schedule, *Advanced Engineering Informatics*, **28**, pp.50-65

Mordue, S., Swaddle, P. and Philp, D. (2016) *Building Information Modeling for Dummies*. West Sussex: Wiley

Morris, P.W.G. (1994) *The Management of Project*. London, Thomas Telford

Naoum, S. G. (1998) *Dissertation Research and Writing for Construction Students*, Oxford: Butterworth-Heinemann

NBS. (2018) *The National BIM Report 2018* [online]. [Accessed 1 August 2018]. Available at <https://www.thenbs.com/knowledge/the-national-bim-report-2018>

North, S., Winch, G.M., Dawood, N., Heesom, D., Kelsey, J., Sriprasert, E. and Mallasi, Z. (2003) *Technical Evaluation: VIRCON Task 12 Report*, Manchester Centre for Civil and Construction Engineering UMIST, a VIRCON report

Olde Scholtenhuis, L.L. and Hartmann, T. (2014) Changing scheduling purposes and evolving 4D-CAD models: a study of planning and realization in a utility project. *International conference on computing in civil and building engineering*, Reston, Virginia, pp. 299 - 306

Patacas, J., Dawood, N., Vukovic, V. and Kassem, M. (2015) BIM for facilities management: evaluating BIM standards in asset register creation and service life, ITcon Vol. 20, pp. 313-331, http://www.itcon.org/cgi-bin/works/Show?2015_20

Patton, M. (1990) *Qualitative evaluation and research methods*. Beverly Hills, CA: Sage.

Patton, M.Q. (2002) *Qualitative research and evaluation methods*. 3rd ed. Thousand Oaks: Sage Publications

Poirier, E., Staub-French, S., and Forgues, D. (2015) Embedded contexts of innovation – BIM adoption and implementation for a specialty contracting SME, *Construction Innovation*, **15**(1), pp.42-65

Randall, T. and Philip D. (2013) *Client Guide to 3D Scanning and Data Capture – The Building Information Modelling (BIM) Task Group PDF* [online]. [Accessed 20 August 2015]. Available at <http://www.bimtaskgroup.org/wp-content/uploads/2013/07/Client-Guide-to-3D-Scanning-and-Data-Capture.pdf>

Roh, S., Aziz, Z. and Pena-Mora, F. (2011) An object-based 3D walk-through model for interior construction progress monitoring, *Automation in Construction*, **20**, pp.66-75

Romigh, A., Kim, J. and Sattineni, A. (2017) 4D Scheduling: A Visualization Tool for Construction Field Operations, *53rd ASC Annual International Conference Proceedings,* pp.395-404

Richert, T. (2017) *What is the Last Planner System?* [blog entry]. [Accessed 12 September 2019]. Available at: <https://leanconstructionblog.com/What-is-the-Last-Planner-System.html>

Ruas, A. (2004) *Change the level of detail in the representation of geographic information*, ASR Thesis, Universite de Marne-la-Vallee.

Sacks, R., Whyte, J., Swissa, D., Raviv, G., Zhou, W. and Shapira, A. (2015) Safety by design: dialogues between designers and builders using virtual reality, *Construction Management and Economics*, **33**(1), pp.55-72

Saunders, M.N.K., and Lewis, P. (2011) *Doing research in business and management: an essential guide to planning your project*. Harlow: Pearson Education.

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2012) *Research methods for business students*. 6th ed. Harlow: Pearson Education

Sawhney, A., Khanzode, A.R., Tiwari, S., Eriksson, C., Cheng I. and Pitman K. (2017) *Building Information Modelling for Project Managers – Royal Institution of Charted Surveyors (RICS) PDF* [online]. [Accessed 22 September 2019]. Available at <https://www.rics.org/globalassets/rics-website/media/knowledge/research/insights/bim-for-project-managers-rics.pdf>

Shen Z. and Issa R.R.A. (2010) Quantitative evaluation of the BIM-assisted construction detailed cost estimates, *Journal of Information Technology in Construction* (ITcon), Vol. 15, pg. 234-257

Shukla, P. (2015) Essentials of Marketing Research – *Bookboon PDF* [online] [Accessed 15 September 2019]. Available at: <https://bookboon.com/>

Smith, D. K. and Tardif, M. (2009) *Building Information Modeling – A Strategic Implementation Guide for Architects, Engineers, Constructions, and Real Estate Asset Managers* [online]. New Jersey: Wiley. [Accessed 30 August 2015]. Available at: <https://www.dawsonera.com/>

Soler, E.T. (2006) *Validation of Qualitative Analytical Methods*. PhD Thesis, Rovira i Virgili University, Spain

Storer, D. (2012) *Six Dimensional Building Information Modeling* [blog entry]. [Accessed 31 August 2015]. Available at: <http://www.hjhigh.com/>

Thomes, J. (2018) *What Is SPSS and Its Importance in Research & Data Analysis?* [blog entry]. [Accessed 2 March 2019]. Available at: <https://medium.com/>

Tolmer, C.E., Castaing, C., Morand, D. and Diab, Y. (2015) Information management for linear infrastructure projects: conceptual model integrating Level of Detail and Level of Development: *Proc. of the 32nd CIB W78 Conference*. University of Technology, Eindhoven 27-29 October. Rotterdam: International Council for Research and Innovation in Building and Construction, pp.735-743

Trani, M.L., Cassano, M., Todaro, D. and Bossi, B. (2015) BIM level of detail for construction site design. A case study, *Procedia Engineering*, **123**, pp.581-589

Trebbe, M., Hartmann, T. and Andre, A. (2015) 4D CAD models to support the coordination of construction activities between contractors, *Advanced Engineering Informatics*, **49**, pp.83-91

Tulke, J., Nour, M. and Beucke, K. (2008) Decomposition of BIM objects for scheduling and 4D simulation, *In Proceedings of the 7th European Conference on Product and Process Modelling in the Building and related Industries*, Sophia Antipolice, France, pp. 653-660

Umar, U. A., Shafiq, N., Malakahmad, A., Nurudin, M. F., Khamidi, M. F., Farhan, S. A. and Gardezi, S. S. S. (2015) *4D BIM application in AEC industry: impact on integrated project delivery. Research Journal of Applied Sciences, Engineering and Technology*, **10**(5), pp. 547-552

Wang, J., Wang, X., Shou, W. and Xu, B. (2014) Integrating BIM and augmented reality for interactive architectural visualisation, *Construction Innovation*, **14**(4), pp.453-476

Wang, X. and Chong, H. (2015) Setting new trends of integrated Building Information Modelling (BIM) for construction industry, *Construction Innovation*, **15**(1), pp.2-6

Winch, G.M. (2010) *Managing Construction Projects.* 2nd ed. West Sussex: Wiley

Winch, G.M., Usmani, A. and Edkins, A. (1998) Towards Total Project Quality: A Gap Analysis Approach, *Construction Management and Economics*, **16**, pp.193-207

Wong, J.K.W. and Zhou, J. (2015) Enhancing environmental sustainability over building life cycles through green BIM: A review, *Automation in Construction*, **57**, pp.156-165

Wong, A.K.D., Wong, F.K.W. and Nadeem, A. (2011) Government Roles in Implementing Building Information Modelling Systems: Comparison between Hong Kong and the United States. *Construction Innovation: Information, Process, Management*, **11**

Wu, I. and Chiu, Y. (2010) 4D Workspace conflict detection and analysis system. *In Proceedings of the 10th International Conference on Construction Applications of Virtual Reality*.

Yoders, J. (2015) *3D Beyond Design: Using BIM Technology for Prefabrication to Remove Waste and Save Money* [blog entry]. [Accessed 5 September 2015]. Available at: <http://www.autodesk.com.au/>

Zhang, J.P. and Hu, Z.Z. (2011) BIM- and 4D-based integrated solution of analysis and management for conflict and structural safety problems during construction: 1. Principles and methodologies, *Automation in Construction*, **20**, pp.155-166

Zhang, S., Teizer, J., Lee, J.K., Eastman, C.M. and Venugopal, M. (2013) Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules, *Automation in Construction*, **29**, pp.183-195

Zhou, W., Heesom, D., Georgakis, P., Nwagboso, C. and Feng, A. (2009) An interactive approach to collaborative 4D construction planning, ITcon Vol. 14, Special Issue Technology Strategies for Collaborative Working, pp. 30-47, http://www.itcon.org/cgi-bin/works/Show?2009_05

Zhou, W., Heesom, D., Georgakis, P. and H.M., Tah, J. (2014) User-centred design for collaborative 4D modelling. *Construction Innovation*, **14**(4), pp.493-517.

SPSS Workshop References

Anon (2012) Educationrealist. *Homework and grades.* [blog entry]. [Accessed 1 February 2018]. Available at: <https://educationrealist.wordpress.com/2012/02/06/homework-and-grades/>

Anon (2018). *Statistics How To* [online]. [Accessed 1 February 2018]. Available at: <https://www.statisticshowto.datasciencecentral.com/probability-and-statistics/correlation-coefficient-formula/>

Argyrous, G. (2011) *Statistics for Research: with A Guide To SPSS*. 3rd ed. London: Saga

Bryman, A. and Cramer, D. (2011) *Quantitative Data Analysis with IBM SPSS 17, 18 & 19.* Hove: Routledge

Gray, C.D. and Kinnear, P.R. (2012) *IBM SPSS 19 Made Simple*. Hove: Psychology Press

Quantitative Specialists (2013) YouTube – *Pearson r Correlation in SPSS - How to Calculate and Interpret Correlation (Part 1, Part 2 and Part 3)* [online]. [Accessed 22 January 2018]. Available at: <https://www.youtube.com/user/statisticsinstructor>

Appendices

Appendix A: Reviewers’ Comments For Publications

Appendix B: Presentations

Appendix C: Posters

Appendix D: Framework processes

Appendix E: Letters, Questionnaires, Contract Review, Responses and Grouped Occupation Roles

Appendix F: Details of the Companies Surveyed

Appendix G: Letters and Validation Feedbacks

Appendix H: Ethical Approval and Survey Participants

Appendix I: Publications

Appendix A: Reviewers' Comments For Publications

Reviewers' Comments: Towards A Framework For Multi-LOD 4D BIM Simulations

Reviews

Review 1	
SECTION A	
SECTION B	
Recommendation and Comments for Authors:	The abstract demonstrates that the authors have a clear understanding of the background context of 4D BIM. They cite key authors in the abstract, but I would urge against this and save this for the literature review. Unless you are studying a particular theory developed by an author it is unusual to do this and I wouldn't recommend it. The paper states that you are going to develop a framework, but I would ask the question how as it is not detailed in the abstract. You need to detail your methodology and outline how your research will go about developing the framework. What is the framework going to show and what is its contribution?

Review 1	
SECTION A	
1. Title reflect paper?:	**1**: (Yes)
2. Keywords appropriate for indexing?:	**0**: (No)
3. Paper purpose stated in introduction?:	**1**: (Yes)
4. Abstract concise and summarises content?:	**1**: (Yes)
5. English and syntax satisfactory?:	**0**: (No)
6. Length paper: 12 pages or less?:	**1**: (Yes)
SECTION B	
Recommendation and Comments for Authors:	**1**: (Requires major changes) The abstract demonstrates that the authors have a clear understanding of the background context of 4D BIM. They cite key authors in the abstract, but I would urge against this and save this for the literature review. Unless you are studying a particular theory developed by an author it is unusual to do this and I wouldn't recommend it. The paper states that you are going to develop a framework, but I would ask the question how as it is not detailed in the abstract. You need to detail your

Review 1	
SECTION A	
1. Title reflect paper?:	**1**: (Yes)
2. Keywords appropriate for indexing?:	**1**: (Yes)
3. Paper purpose stated in introduction?:	**1**: (Yes)
4. Abstract concise and summarises content?:	**1**: (Yes)
5. English and syntax satisfactory?:	**1**: (Yes)
6. Length paper: 12 pages or less?:	**1**: (Yes)
SECTION B	
Recommendation and Comments for Authors:	**3**: (Accept as it stands) Authors have addressed the key comments which were made during in the initial review. The purpose of the framework is stated. The paper appears to have been proof read and this improves its presentation. Would like to encourage the authors in the future to reflect on the story that they are telling and the contribution that their research is making to the community. This comes with more discussion and a greater attempt to place the research in context. The paper as it stands is very factual about what the authors feel should be in the framework, and I feel to have wider impact a broader discussion could be presented. However, I view this as developmental beyond this conference.

RE: Re-submitted the publication paper

[redacted]

Thu 13/07/2017 16:24

Inbox

To: Butkovic, Bogdan [redacted]

Hello Bogdan

Many thanks for this. Your paper has been sent back to the reviewer. We'll let you know just as soon as we hear something back.

Best wishes

[redacted]

From: Butkovic, Bogdan [redacted]
Sent: 10 July 2017 01:57
To: [redacted]
Subject: Re: Re-submitted the publication paper

Dear [redacted],

Thank you very much for your email of 8th June. I have worked on the update of the publication and added the details so I have submitted it to the conference for review. This is just to inform you about my submission and I look forward to hearing from you.

Kind Regards,

Bogdan Butkovic

From: [redacted]
Sent: 08 June 2017 15:14
To: Butkovic, Bogdan
Subject: RE: [redacted] notification for paper 130

Hello Bogdan

I have been in touch with your reviewer. Reviewer doesn't know what happened with the earlier review that the reviewer typed in but which doesn't now appear. Reviewer thinks maybe reviewer pressed the wrong button ....

Anyway, here are the review comments now given below.

Best wishes

[redacted]

This paper explores an interesting area of research and one which the authors have established that is under researched. The intention to develop a framework is a good one as this can be the basis for further enquiry.

Felt the paper could do with a proof read to make sure that all the sentences make sense and communicate the intended message. There is no doubt the authors understand the field, but there is a need to look at your story telling and how you link this together to establish your contribution to the field from this work. My main comments for development reflect the need to provide a higher level of discussion. It reads very factual and informative rather than providing evaluation which provokes questioning and enquiry. An effective literature review needs to evaluate what you are presenting and provide a stronger level of discussion (exploring the implications of what you are presenting etc).

Need to make sure that you reference the figures in the body of the paper, and importantly help the reader understand what you are presenting and how to interpret it. Section 3 is very short and I would suggest that you have a stronger discussion of the figure before proceeding to the conclusions.
The limited discussion prior to the conclusions leaves us with a need for a higher level of discussion to help you present and justify the framework. Where you are lacking is in positioning your work in relation to the body of research in this area and spelling out your contribution.

I would advise that you change the title of section 1.1 from paper review to something different. Even literature review would be better.

Section 1.2 the title needs to be reworded.

From: Butkovic, Bogdan [[redacted]]
Sent: 07 June 2017 23:26
To: [redacted]
Subject: Re: [redacted] notification for paper 130

Dear [redacted],

In reference to the comments received from International Research Conference team on 25th May I would appreciate if you can clarify if the raised feedback are related to the full paper (actual publication paper) submitted or for abstracts only (initially sent to you)?

I would appreciate if you response to me as I am currently working on the revised version of the paper.

Kind Regards,

Bogdan Butkovic

From: [redacted]
Sent: 25 May 2017 16:52
To: Butkovic, Bogdan
Subject: [redacted] notification for paper 130

Dear Bogdan Butkovic

Thank you for your paper submission Towards a framework for multi-LOD 4D BIM simulations to the International Research Conference 2017 at the University of Salford, UK. Your reviewer has asked that major changes be made - please see their comments below.

If you feel this is possible please can you make the requested changes and re-submit the paper as soon as practically possible.

If you have any queries please contact [redacted]

Regards
International Research Conference team

----------------------- REVIEW 1 ---------------------
PAPER: 130
TITLE: Towards a framework for multi-LOD 4D BIM simulations
AUTHORS: Bogdan Butkovic

1. Title reflect paper?: 1 (Yes)
2. Keywords appropriate for indexing?: 0 (No)
3. Paper purpose stated in introduction?: 1 (Yes)
4. Abstract concise and summarises content?: 1 (Yes)
5. English and syntax satisfactory?: 0 (No)
6. Length paper: 12 pages or less?: 1 (Yes)

Recommendation and Comments for Authors: 1 (Requires major changes)

----------- Recommendation and Comments for Authors -----------
The abstract demonstrates that the authors have a clear understanding of the background context of 4D BIM. They cite key authors in the abstract, but I would urge against this and save this for the literature review. Unless you are studying a particular theory developed by an author it is unusual to do this and I wouldn't recommend it.
The paper states that you are going to develop a framework, but I would ask the question how as it is not detailed in the abstract. You need to detail your methodology and outline how your research will go about developing the framework. What is the framework going to show and what is its contribution?

Reviewers' Comments: The Need For Multi-LOD 4D Simulations in Construction Projects

RELATED TO THE PAPER IN GENERAL

- How relevant is your judgement?

  Very – this topic is close to my field of research

- In a phrase, what is the substance of the paper?

  The paper proposes a conceptual framework for considering different classifications for levels of detail for (1) geometries, (2) tasks in a construction schedule, (3) granularity in parts and pieces of the geometries, all for having flexibility in creating dynamic 4D models.

- Is this work different from other previous or parallel efforts? If so, how?

  Yes. This is thought provoking piece that is dedicated for different LODs that could be applicable to 4D simulation.

- Is the English language correct and concise?

  Generally satisfactory. There are several sentences with grammatical errors that could be fixed with a thorough proofreading.

- Is the paper well organised? How can its organisation be improved?

  The organization of the paper is satisfactory.

- Are the illustrations clear and do they support the paper?

  Yes, for the most part. There are two Figure 4. Please discuss the parts of first Figure 4 that were not discussed in the main text (e.g. is the construction planning approach really relevant to 4D simulation? Why? What is planning horizon?).

  Please revised the graphics for the second figure 4 to make different ideas clearer. Please also be consistent in the role of clouds (a person specifies LOD or a document like BIM EX PLAB specifies LOD, lets differentiate between the media and their creators).

RELATED TO THE INTRODUCTION

- Does the summary summarize or does it introduce the paper?

  Yes. It summarizes the paper.

- Is the introduction repetitive with other similar efforts?

  To my knowledge, it is not repetitive.

- Are the related or parallel efforts referenced?

  Yes.

- Is the problem well described?

  Yes. The problems with the existing 4D modeling approaches are outlined.

RELATED TO THE CORE

- Do the authors explain the original aspects of their work?

  Yes.

- Are the criteria for the design or implementation clear?

  This is not an implementation. It's a conceptual framework supported by a survey.

- If it is an implementation, do the authors describe the platforms, libraries, and other environments that are essential for the implementation?

  Not applicable. A conceptual framework is proposed, and the survey confirmed that some practitioners are interested in future developments in this area.

- Are the examples explained and clear?

  The paper can benefit from more examples that show potential levels for different LOD categories. Since the authors claim that they are currently implementing this in real-world projects, providing some examples can help the readers understand the implementation aspects. In its current form, the paper just throws the idea.

- Can the success or failure of the effort be assessed?

  The paper proposes the idea and it is not an actual implementation.

RELATED TO THE CONCLUSIONS

- Are the conclusions clear and conclusive? Are they supported in the paper?

  Yes.

- Do the authors succeed in proving the original hypothesis?

  Not applicable.

- Is there an objective discussion of the research results?

  Yes.

- Additional Comments:

  Please address the following:

  - 4D simulation often show temporary structure, equipment, and site logistics. What is the significance of these items in the framework? Can (or Should) LODs consider these elements?
  - There are different trends in creating 4D simulations. Conventionally, 4D simulations show snapshots of a projects building products at certain time intervals. But, for equipment heavy projects and projects with geometric complexity, some modelers do animate equipment and building objects to show for example how certain elements should be moved or transported to their installation location. Can (or Should) LODs or the framework consider these scenarios? (note that in Fig 3, the respondents are not big fans of hourly LODti).
  - Can you discuss the level of effort one should put into a model to create a 4D simulation with high LODs? Working with a prominent structural engineering firm in the U.S., I came to know that structural engineers do not necessarily share their models with contractors, and even when they do, their model is at best in lower LODs. Furthermore, the models are at the design intent level, and they do not necessarily have means and methods of construction and the construction level granularity (many drawings give the contractors different options for rebar laps, welding, etc.). So I think that if a contractor wants an "hourly" 4D simulation, the contractor itself should pay for the model. So how much effort/time/money does the contractor spend on this? Who is involved in the modeling, the GC itself or the GC and all the subs? Does this have a viable return on investment for the contractor or for the client?
  - 4D simulation here is from a General Contractor's perspective? With high LODti, do the subcontractors' schedule need to be combined for accurate 4D simulation? A GC does not necessarily track that level of detail on behalf of the subs.
  - Overall, I believe that the practitioners in the construction industry are open to these ideas until they are asked to pay for it. The ideas presented in this paper are thought provoking but require more details to inform the readers on the feasibility of actual implementation (I believe this not just about the capability of software packages; considering the financial and organizational feasibility and transitioning from the existing practice of creating project models and schedule to what you are proposing is important to discuss).

WHAT IS YOUR OVERALL RECOMMENDATION TO THE EDITORS:

Requires major modifications which can be checked by the editor

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Reviewers' Comments: The Framework Validation for Dynamic 4D BIM Simulations

Reviews

Review 1	
Overall evaluation:	**2**: (accept) This abstract on 4D simulation has been accepted. The abstract and the full paper must include who are the beneficiaries.

Review 2	
Overall evaluation:	**3**: (strong accept) - Excellent paper and well-constructed. Thorough research and a high volume of primary research undertaken. - I would suggest possibly including a glossary of terms as the varieties of LOD was somewhat confusing at the outset. - Strong recommendation - The paper needs to be reduced to the required 10-page limit

Review 3	
Overall evaluation:	**3**: (strong accept) The paper sought an empirical way to identify the needs and inputs of LOD 4D BIM from the current industrial practitioners that strongly support the ongoing research to constitute the proposed research framework. The literature part is informative and extensive to highlight the 4D BIM research trends and modern commercially available tools' features in the LOD aspect. It is thus positive to enhance the relationship among LODti, LODg and LOD4d against the research background that less research is available to help address the topic. The delivered information is valuable from the paper that LOD4d has not only academic attraction of new LOD 4D method but also real desires from industry professionals with potential tools development. Its technical issues would be highlighted a bit so that to give reviews/readers some clues about potential realization as feasibility proposals.

Appendix B: Presentations

Towards A Framework For Multi-LOD 4D BIM Simulations – International Research Conference: Shaping Tomorrow's Built Environment, University of Salford, UK

https://www.cibworld.nl/site/news/newsletter.html?year=2017&number=1

https://www.cibworld.nl/site/news/newsletter.html?year=2017&number=2

Dropbox download link:

https://www.dropbox.com/s/rsj59w4gwv08c4w/IRWAS2017%20-%20Bogdan%20B.pdf?dl=0

The Framework Validation for Dynamic 4D BIM Simulations – 1st International Conference on Construction Future 2018 (ICCF2018), University of Wolverhampton, UK

https://www.cibworld.nl/site/news/newsletter.html?year=2018&number=4

https://www.cibworld.nl/site/news/newsletter.html?year=2018&number=5

Dropbox download link:

https://www.dropbox.com/s/4psz1x54zrz9yfy/ICCF2018%20-%20Bogdan%20B.pdf?dl=0

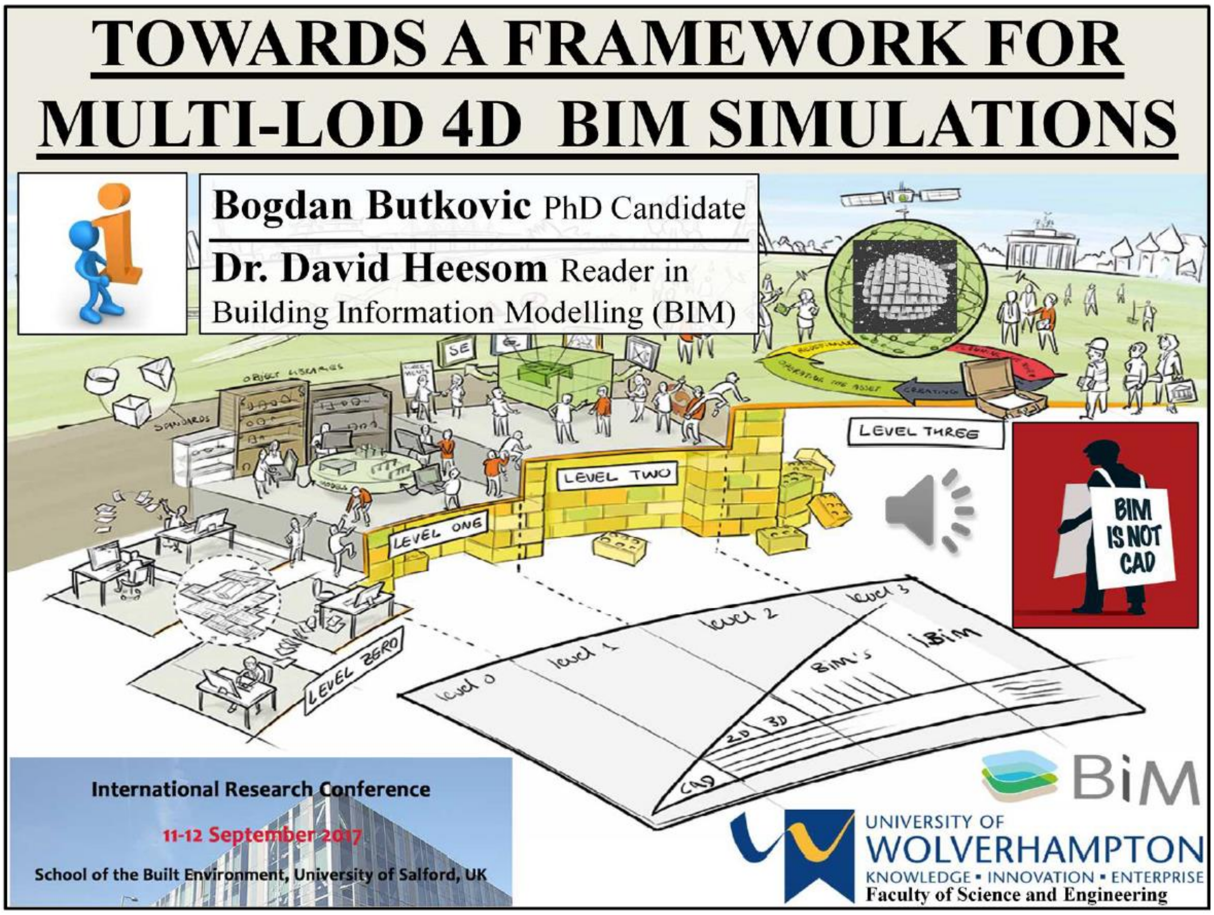
IMPACT OF 4D LOD (LEVEL OF DETAIL) ON COMMUNICATION IN CONSTRUCTION PROJECTS – BEERS (Built Environment & Engineering Research Seminars), University of Wolverhampton, 11th April 2018

https://www.wlv.ac.uk/about-us/news-and-events/events/2018/april/beers.php

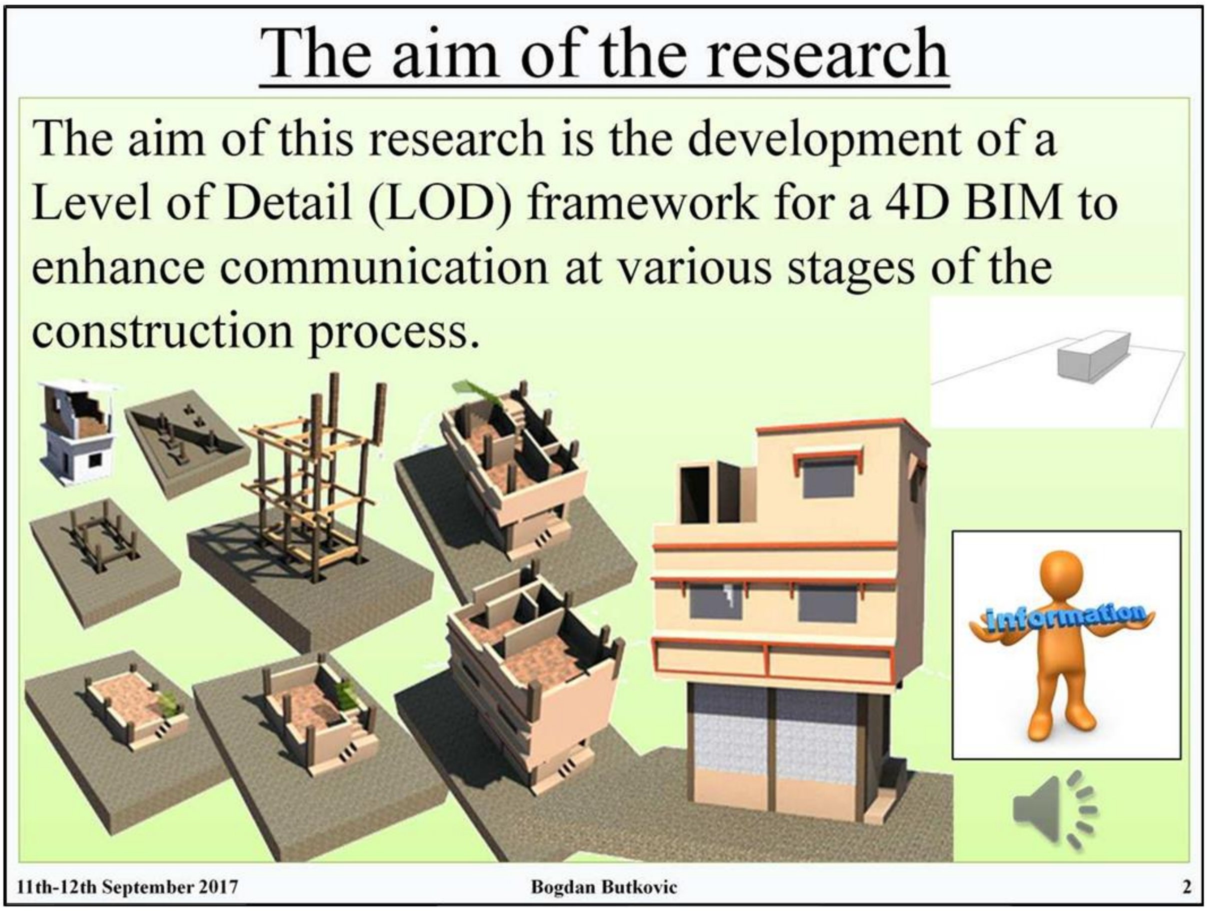
Dropbox download link:

https://www.dropbox.com/s/afrxb1ccsavvi66/BEERS%2011th%20April%202018%20-%20Bogdan%20B.pdf?dl=0

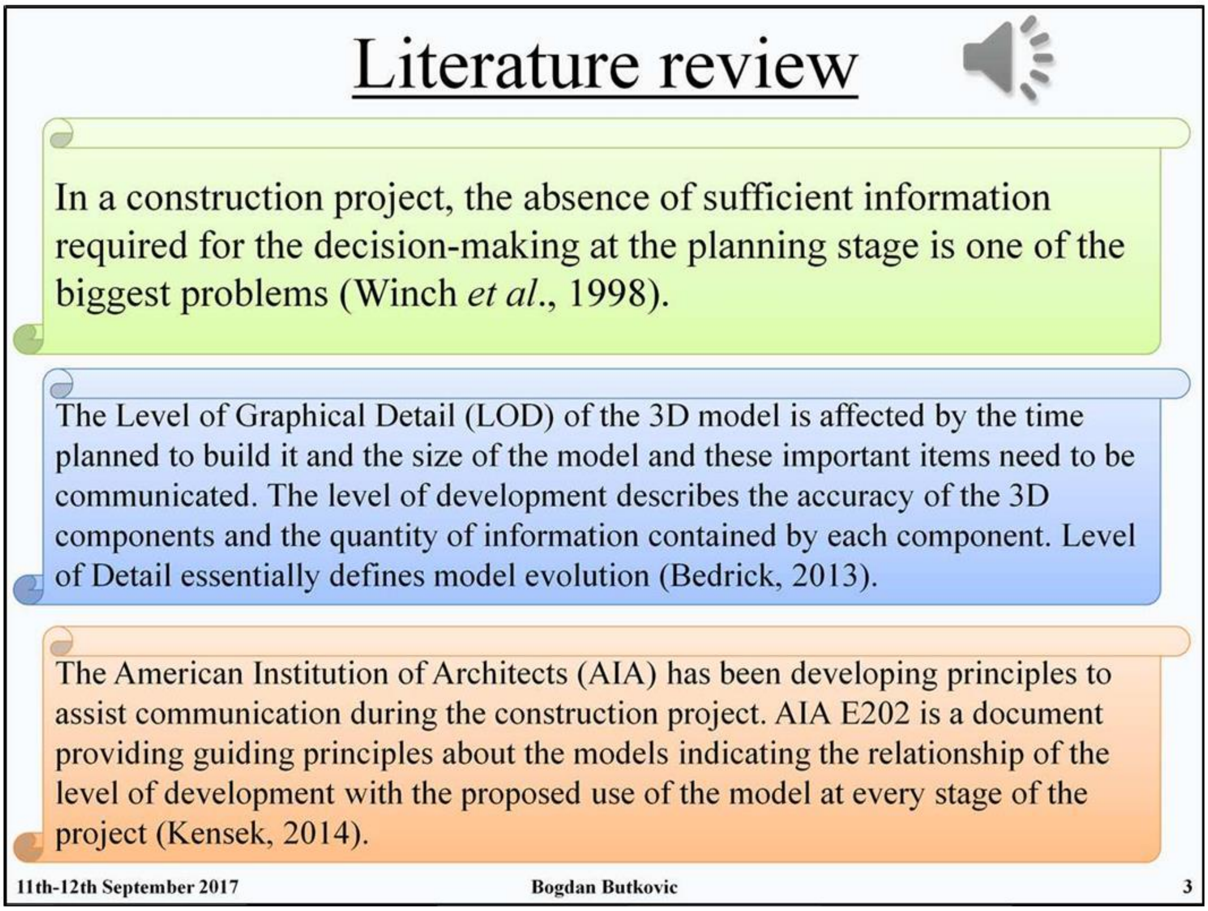
Towards A Framework For Multi-LOD 4D BIM Simulations



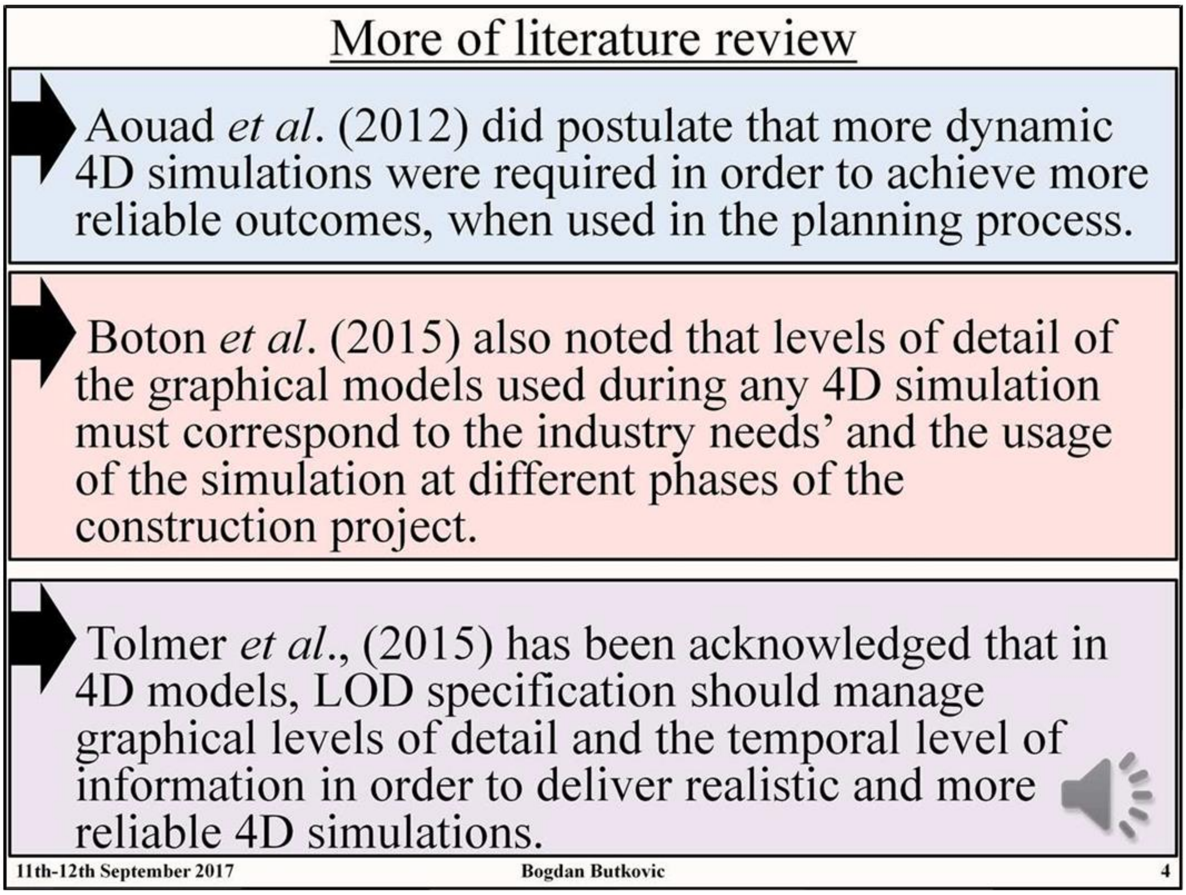
"My name is Bogdan Butkovic, I am a PhD Candidate in the Faculty of Science and Engineering at the University of Wolverhampton and my supervisor is Dr. David Heesom, Reader in Building Information Modelling. I have been doing my research on a 4D LOD in order to achieve more dynamic 4D model. I am hard of hearing and it would be more convenient for me to do the slide presentation with the text to speech demonstration."



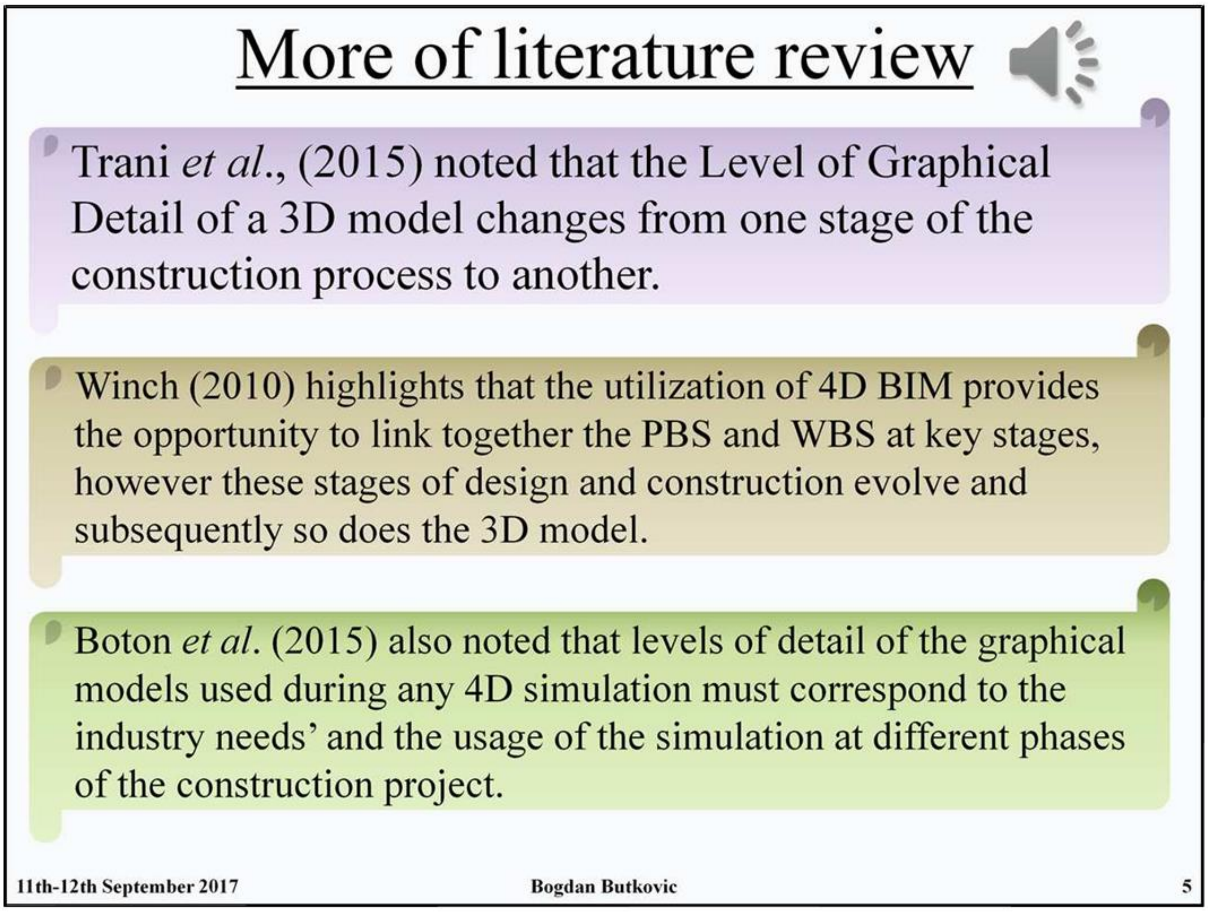
"4D simulations integrate both 3D components and construction activities schedules. Therefore, the BIM level of development incorporates geometry and non-graphical information. For that reason, a 4D LOD requirement must manage both the graphical level of detail and the temporal level of detail."



"The literature review helped acknowledged the importance of information communicated among construction participants. Researchers pointed out the inevitability for 4D dynamics."



"The literature review helped to recognize even as a wide range of research has been undertaken over the last 15 years in the field of 4D modelling, little has been presented in terms of developing an approach to understand the specific level of detail required for 4D simulations."



"The solution for comprehending collaborative 4D planning is in the collaborative planning workflow. Starting with a shared 3D model that is manageable by all designers, this allows them to foster a collaborative scheduling session and continue work with multilevel communication. This interaction among planners allows them to perform their planning more effectively. Using a 3D model as a start, everyone involved in the planning process is able to evaluate the design, discuss planning approaches with each other and propose solutions."

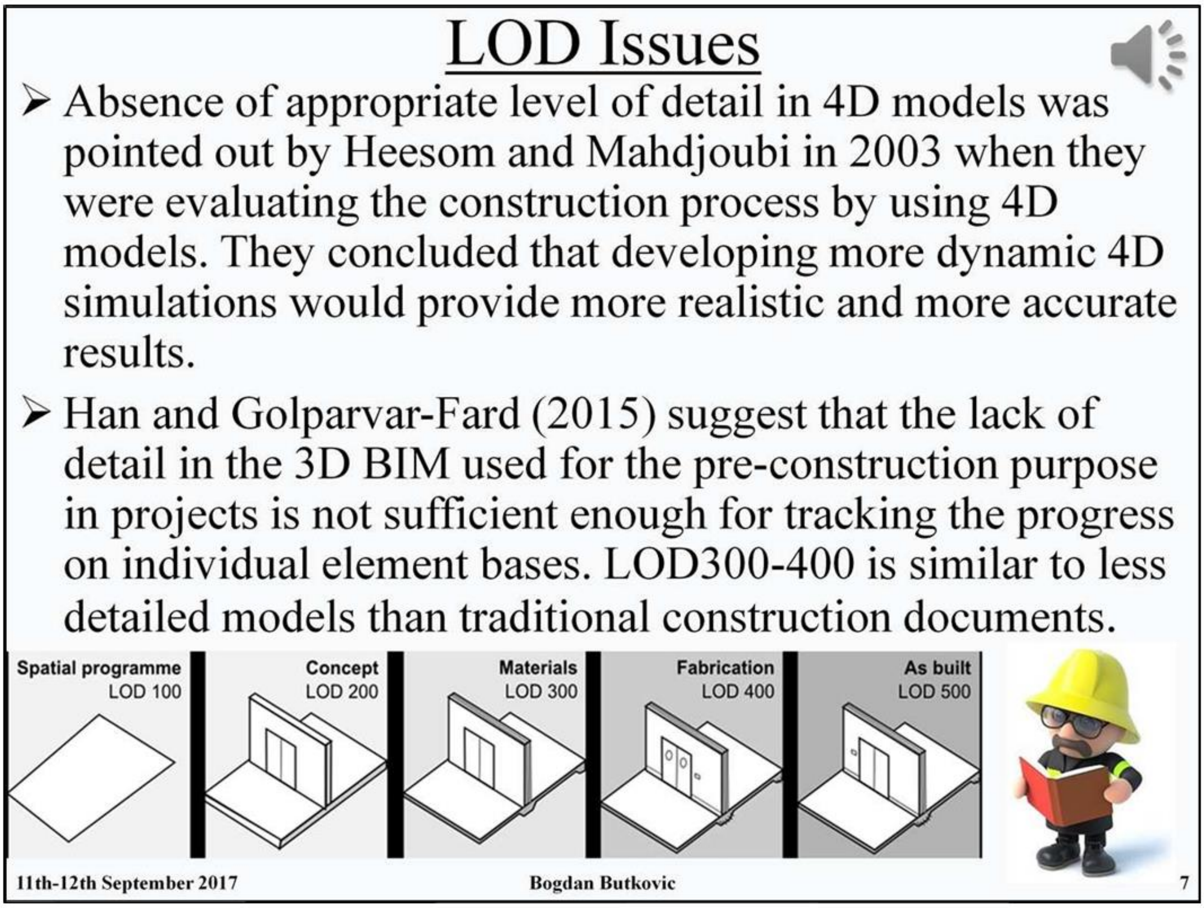
Technology for 4D and current applications

Company / *Tool*	**Description**	**Linkage**	**Multiple LOD simulation**
Bentley / *Project Wise Navigator*	Provides Project and analyse wise schedule simulation. Import 2D and 3D design files difference sources	Importing and connecting schedule information from Microsoft Project, Excel or Primavera. Reviewing interfaces (clashes) and viewing and analysing schedule simulations	No
Autodesk / *Navisworks Suite JetStream TimeLiner*	Supports various numbers of BIM formats and has overall very good visualization capabilities Permits the importation of schedules from a variety of sources	Supports manual and automatic linking to imported schedule data from variety of schedule applications Allows the user to join the items in the model with the tasks and simulate the schedule	Use of the images and animations created bring simulation up to date automatically if the model is changed.
Innovaya / *Visual Simulation*	Combines BIM objects with planning activities to complete a 4D construction. Generates simulation of construction process	Increases the project communication, synchronization and logistic scheduling. Links 3D design data in DWG with Microsoft Project or Primavera	No
Syncro Ltd / *Syncro 4D*	New 4D tool with improved scheduling and project management	Covers risk and resource analyses features and include built in tools to visualize risk, buffering and recourse usage in addition to 4D visualization	No
VicoSoftware / *Virtual Construction*	5D construction planning system which covers Constructor, Estimating, Control and 5D Presenter	Schedule data can be imported from Microsoft Project or Primavera and any changes in scheduling system are automatically reflected in the 4D visualization	No

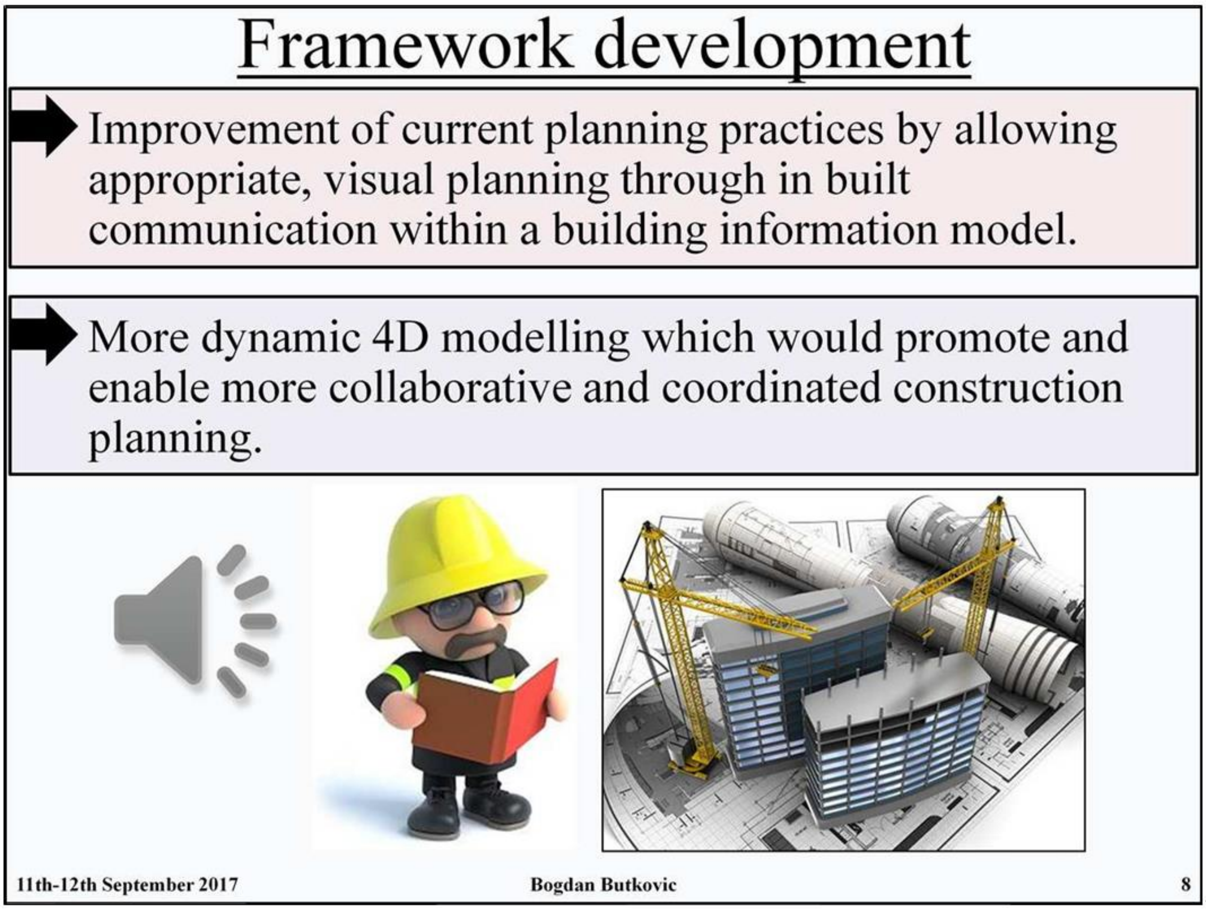
11th-12th September 2017 **Bogdan Butkovic** **6**

"If a 3D model and the schedule are established appropriately the connecting of the two elements together to form the 4D model should be a direct process. Lately some software applications have been technologically advanced to provide automated connecting however there is still:

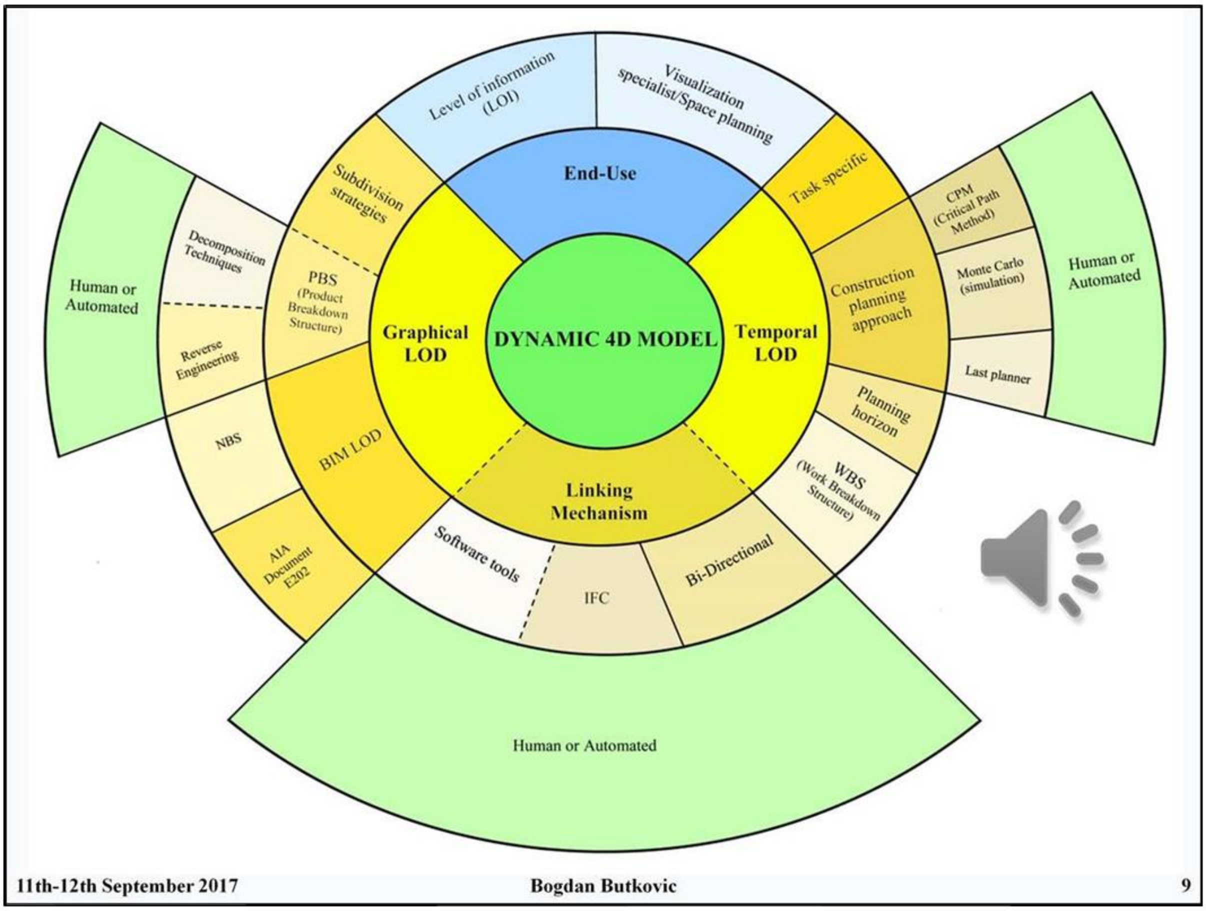
- *The need for two or more software applications in order to integrate design and planning information*
- *The absence of construction plan information as the construction activities could not all the visually presented.*
- *No clear evaluation and duration of activities in the project*
- *Persistent need for the Gantt chart to present activities' relationships*
- *The project team still have to modify or optimize the schedule manually for a 4D model in order to completely recognize its benefits*
- *Lack of more dynamic 4D simulation in order to achieve more reliable outcomes."*



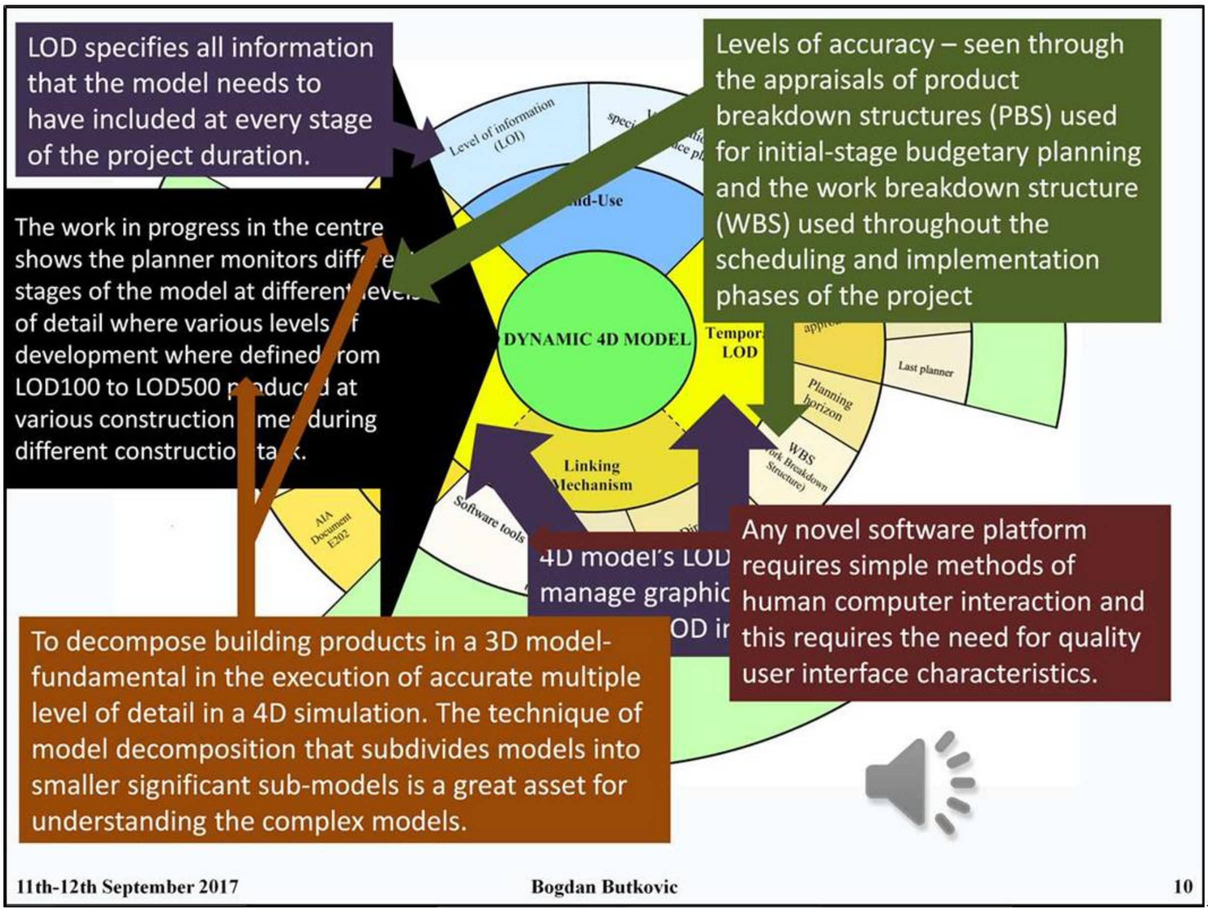
"There are two critical factors that exist when thinking towards the end usage of a 4D model. Firstly, the planning horizon used and subsequently the time period between state changes in the simulation i.e. 1 day, 1 week etc. Secondly having geometry at a level of granularity that can be linked to tasks produced at the relevant planning horizon to present an accurate reflection of the construction sequence. Thus far, limited research has been undertaken on the critical issue of 4D LOD issues although the importance of the level of detail and its impact on BIM projects has been indicated repeatedly in the available literature."



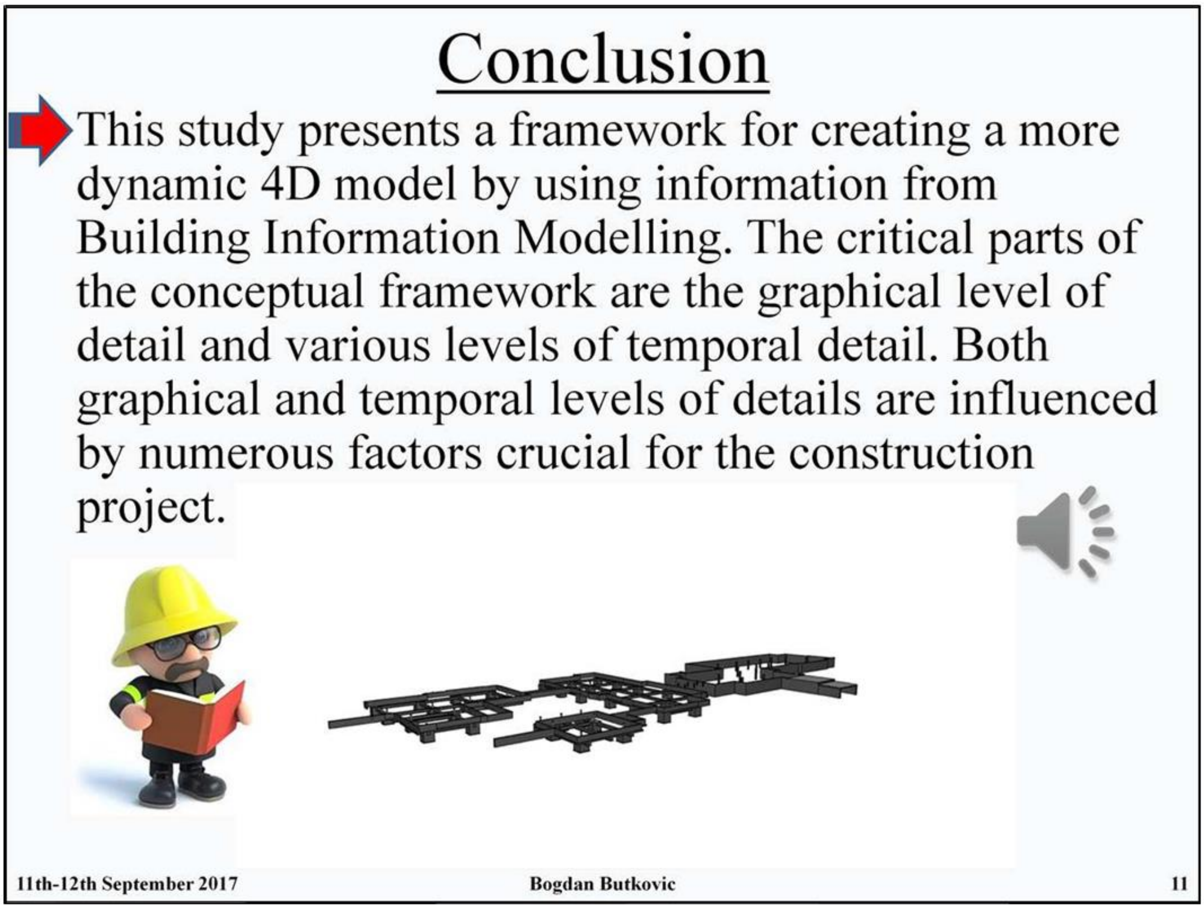
"The anticipated framework attempts to focus on key issues identified in the literature. This conceptual framework is set to address problems acknowledged within current construction planning practice and the drawbacks and future capabilities of 4D methodologies through the application of new technological solutions, directed towards a strong and innovative approach to construction plan creation."



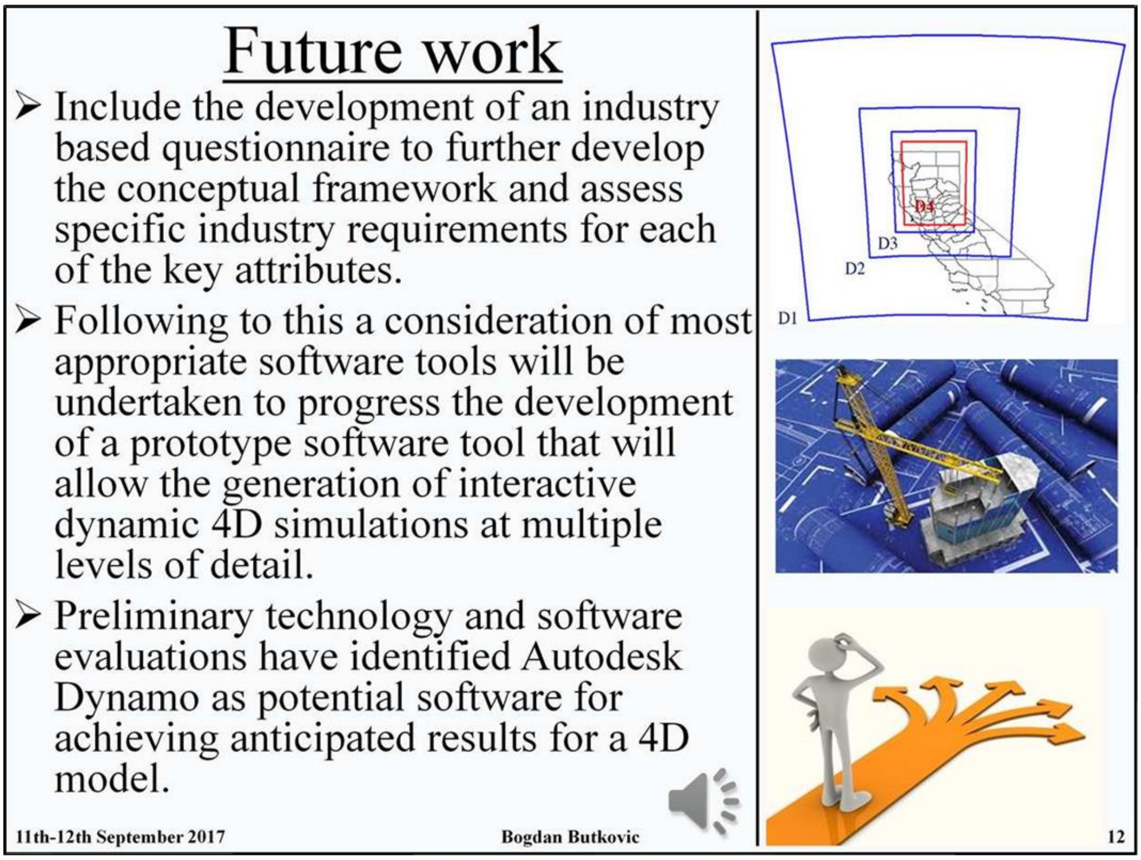
"The focus of the framework is the Dynamic 4D model such that the planner can produce and utilize more realistic and representative simulations of the construction process at various temporal and graphical resolutions. The construction planner should have the ability to decompose a single component into sub elements according to areas and related activity into sub activities. This technique proposed by Akbas and Fischer from 2002 is postulated in the framework. These areas can be created at different levels of detail to contribute to a more comprehensive view of the schedule. Many parts, including the shape of the construction zone, import the efficiency level used during the progress of the dynamic phase of the geometry axes."



"The proposed framework emphasizes necessity for planning, controlling and coordinating construction phases using visualized analysis of conflicts and clashes in models even before construction works."

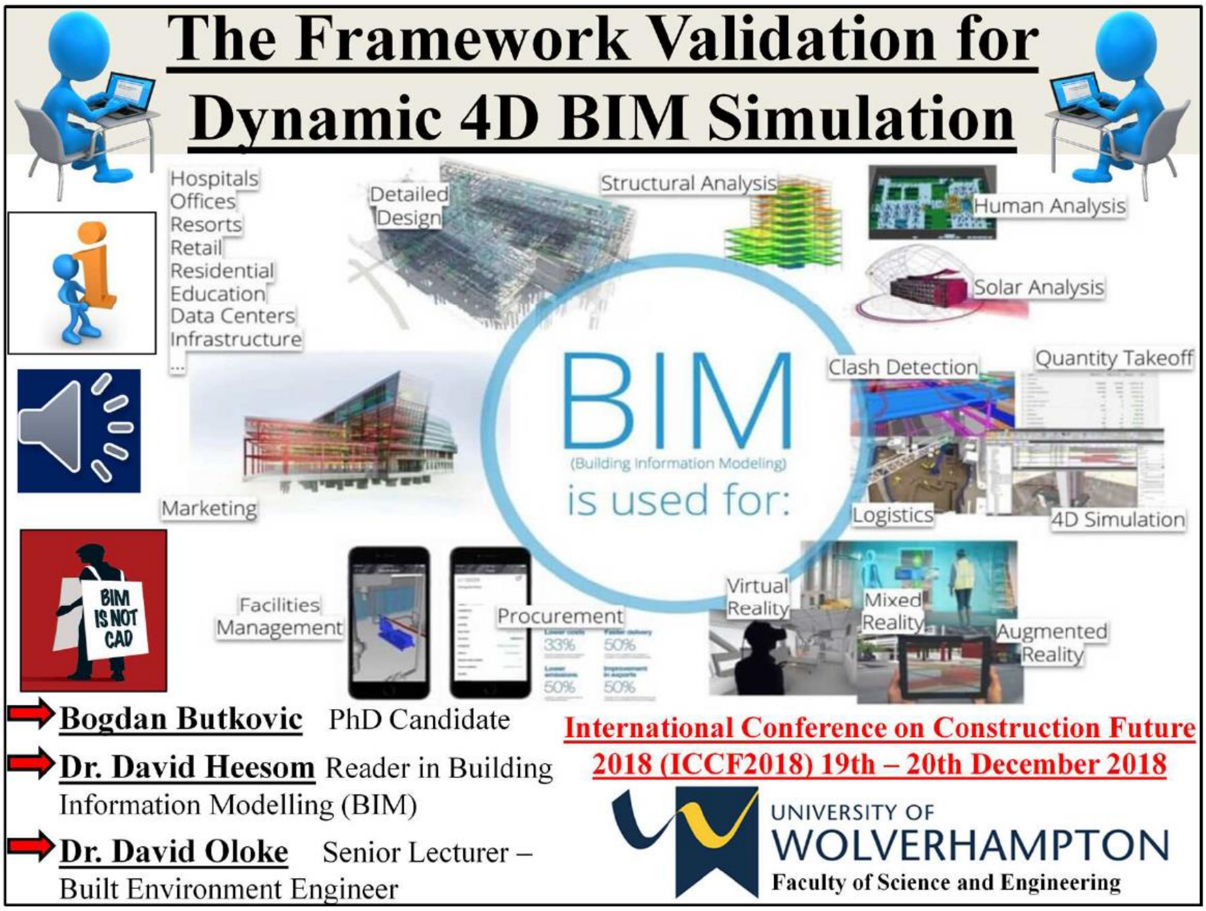


"4D is evolving as a construction planning technology to address some of the challenges currently faced by the AEC industry. 4D planning has the ability to increase the visualization of the building design and construction. This 4D technology can improve the visualization but still needs time to reach the maturity. Where 4D technology has been included the outcomes indicate saving and a growth in productivity. The use of 4D shows that it can save money on construction projects by recognizing difficulties seen in earlier construction projects and by avoiding re-work during the project."

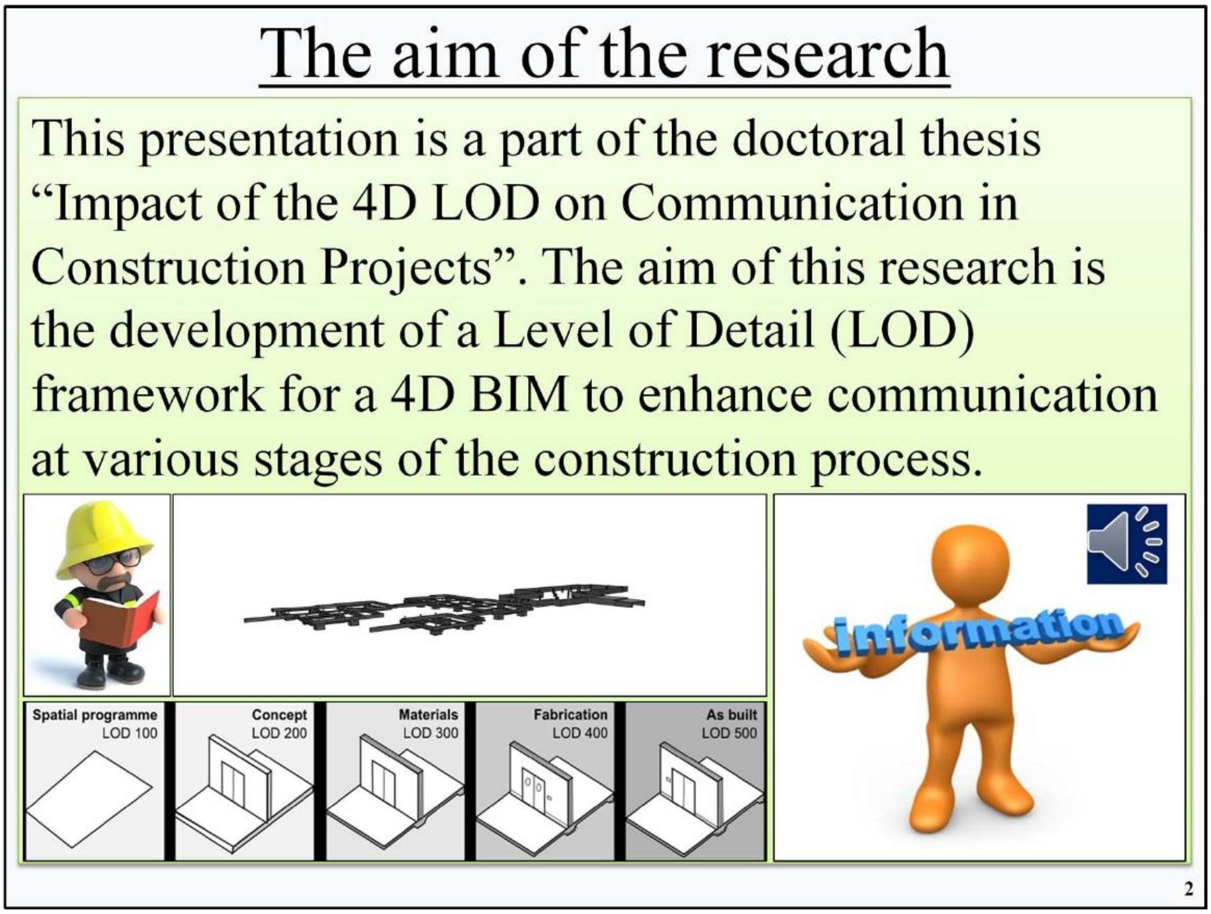


"Software Autodesk Dynamo has the potential to develop a prototype due to having the ability to obtain geometric control within in a BIM environment and externally to the underlying project planning database that is not possible when using a conventional modelling interface."

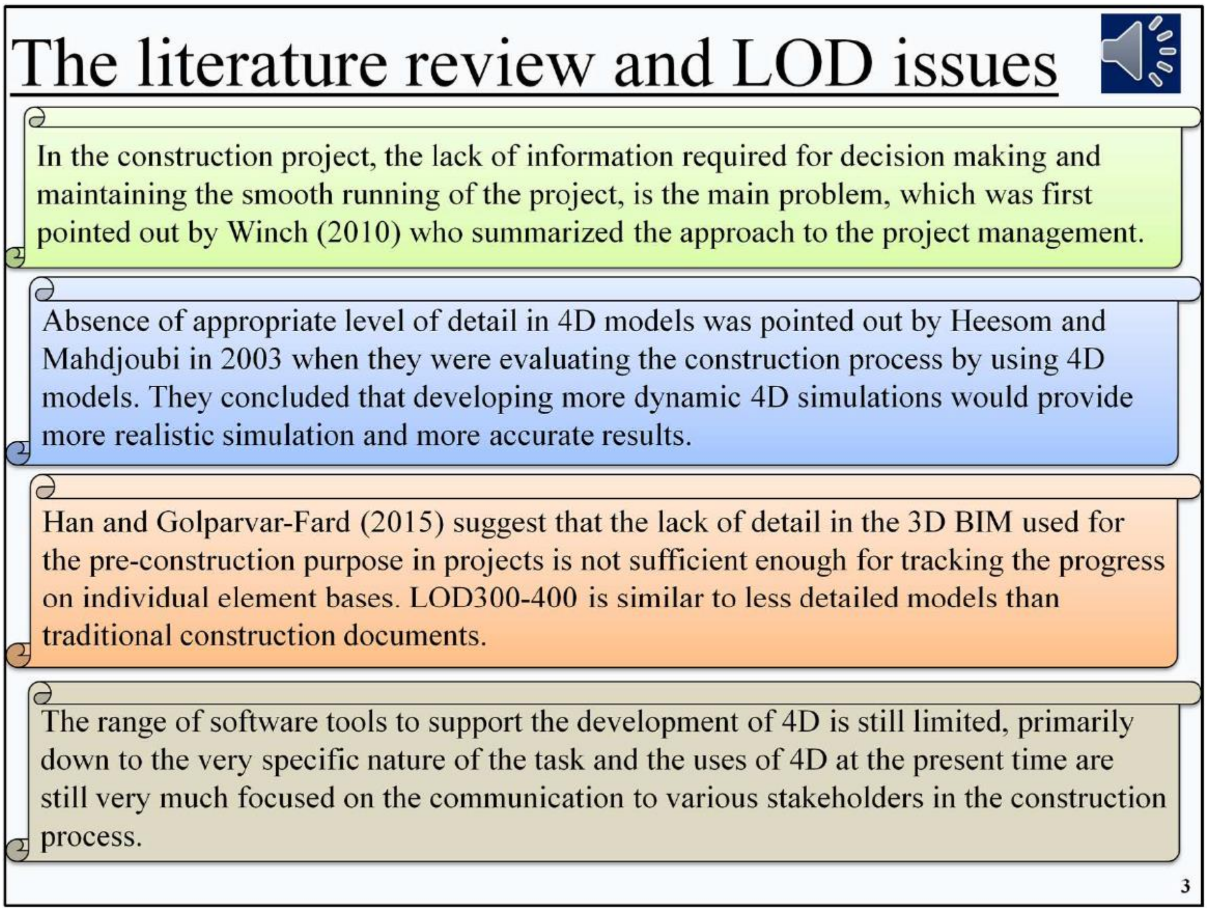
The Framework Validation for Dynamic 4D BIM Simulations



"My name is Bogdan Butkovic, I am a PhD Candidate in the Faculty of Science and Engineering at the University of Wolverhampton and my supervisors are Dr. David Heesom, Reader in Building Information Modelling and Dr. David Oloke, Senior Lecturer, Built Environment Engineer. I have been doing my research on a 4D LOD in order to achieve more dynamic 4D model. I am hard of hearing and it would be more convenient for me to do the slide presentation with the text to speech demonstration."



"The slide reveals the aim of the ongoing study which is the creating of the suitable Framework for more dynamic 4D simulation."



"4D simulations integrate both 3D components and construction activities schedules. Therefore, the BIM level of development incorporates geometry and non-graphical information. Thus, a 4D LOD requirement must manage both the graphical level of detail and the temporal level of detail. The literature review helped acknowledged the importance of information communicated among construction participants. Researchers pointed out the inevitability for 4D dynamics. Although a wide range of research has been undertaken over the last 15 years in the field of 4D modelling, little has been presented in terms of developing an approach to understand the specific level of detail required for 4D simulations."

"Lately some software applications have been technologically advanced to provide automated connecting however there is still:

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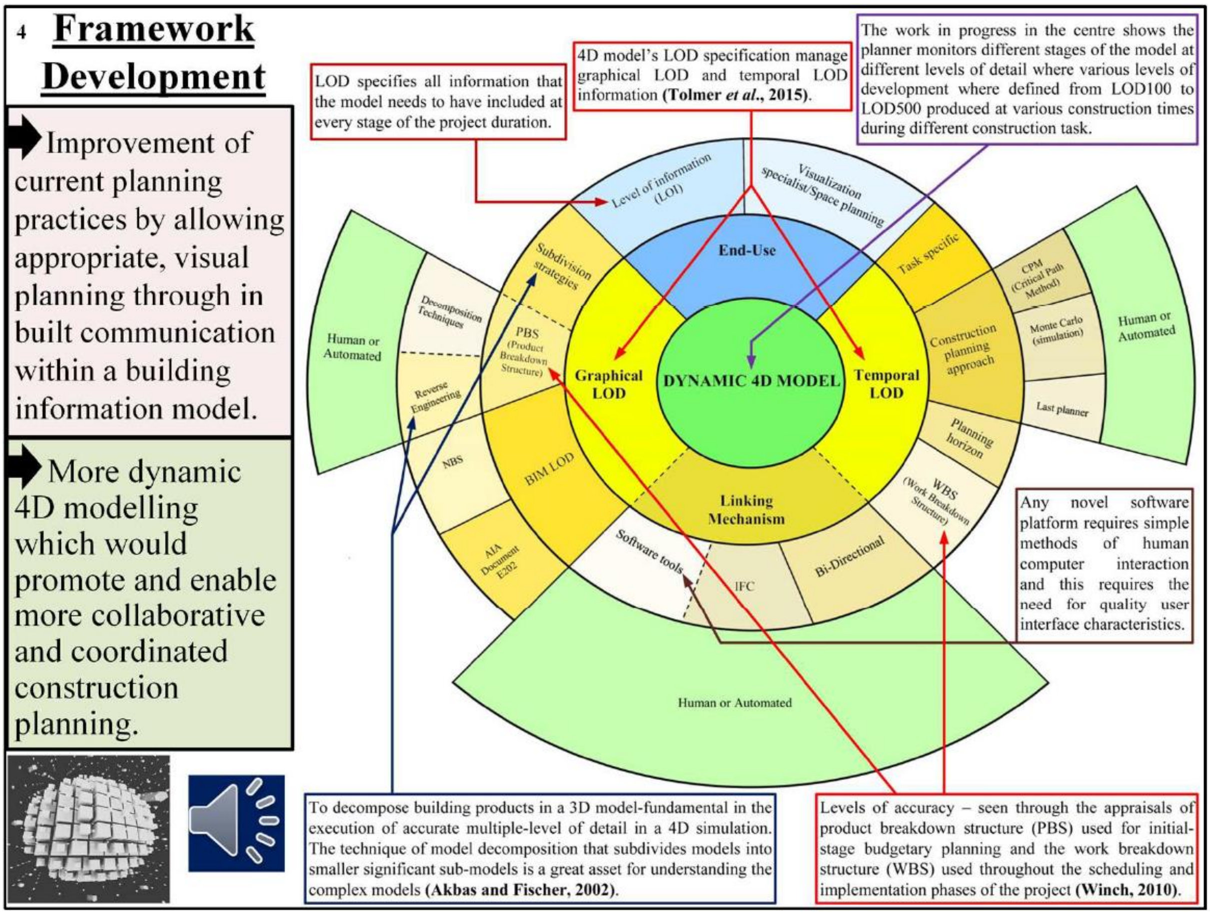
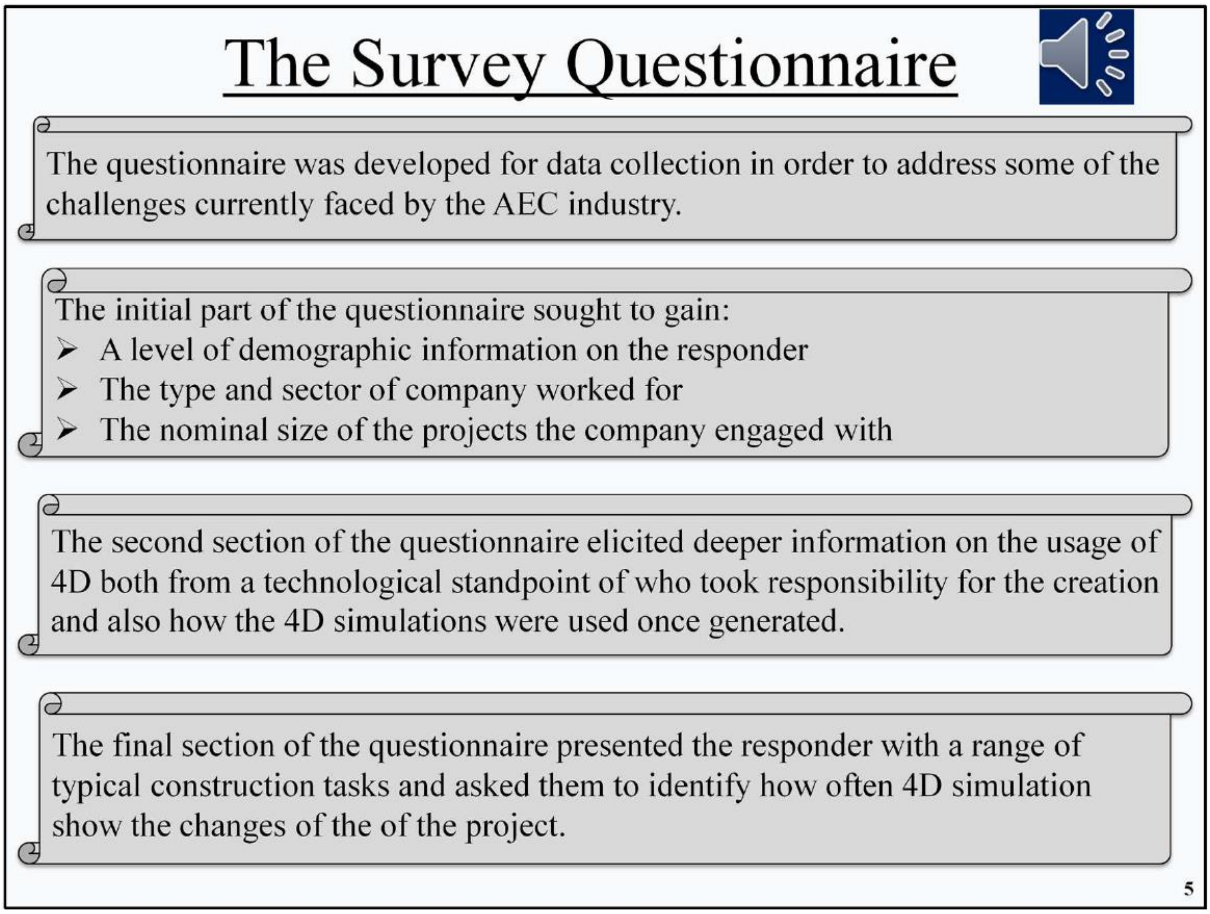
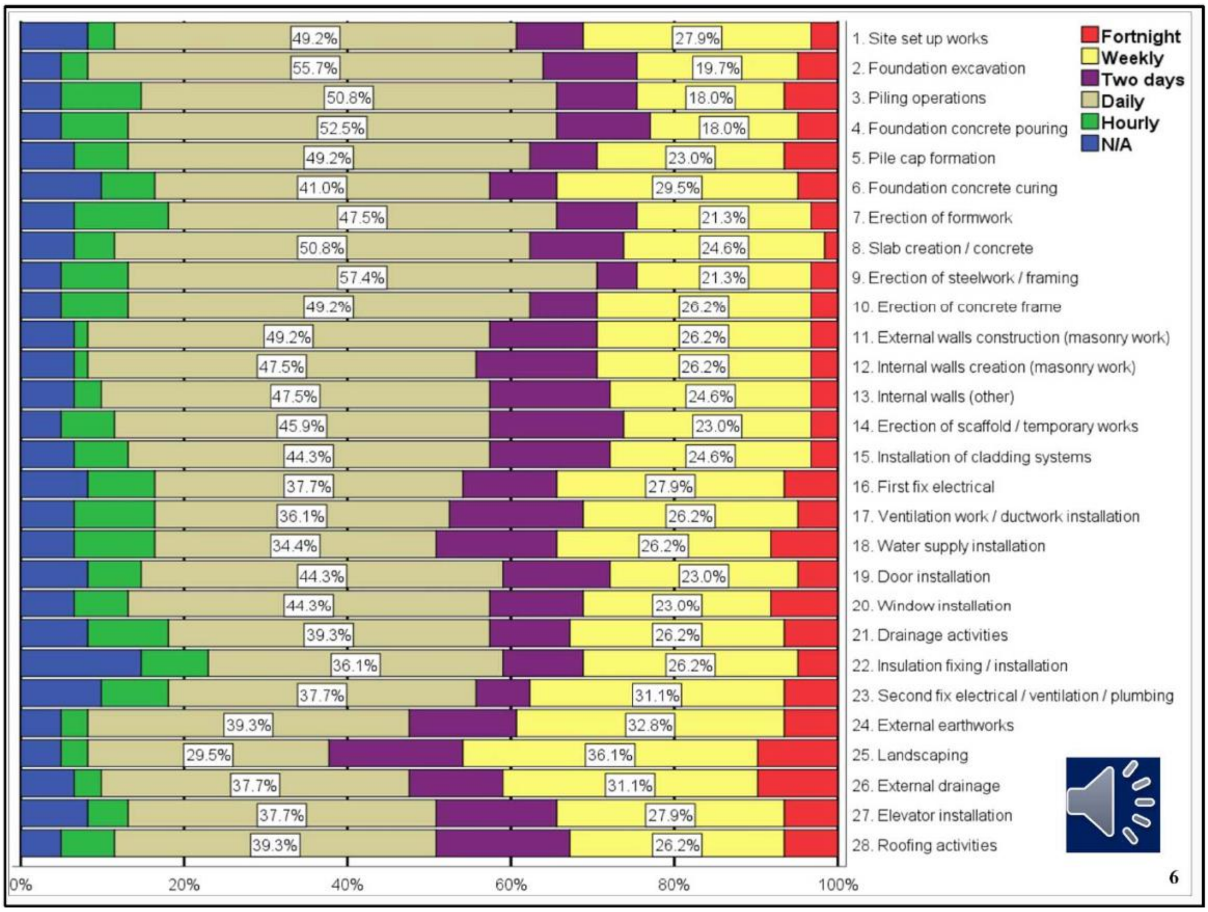
- *Persistent need for the Gantt chart to present activities' relationships*
- *The project team still have to modify or optimize the schedule manually for a 4D model in order to completely recognize its benefits*
- *Lack of more dynamic 4D simulation in order to achieve more reliable outcomes"*



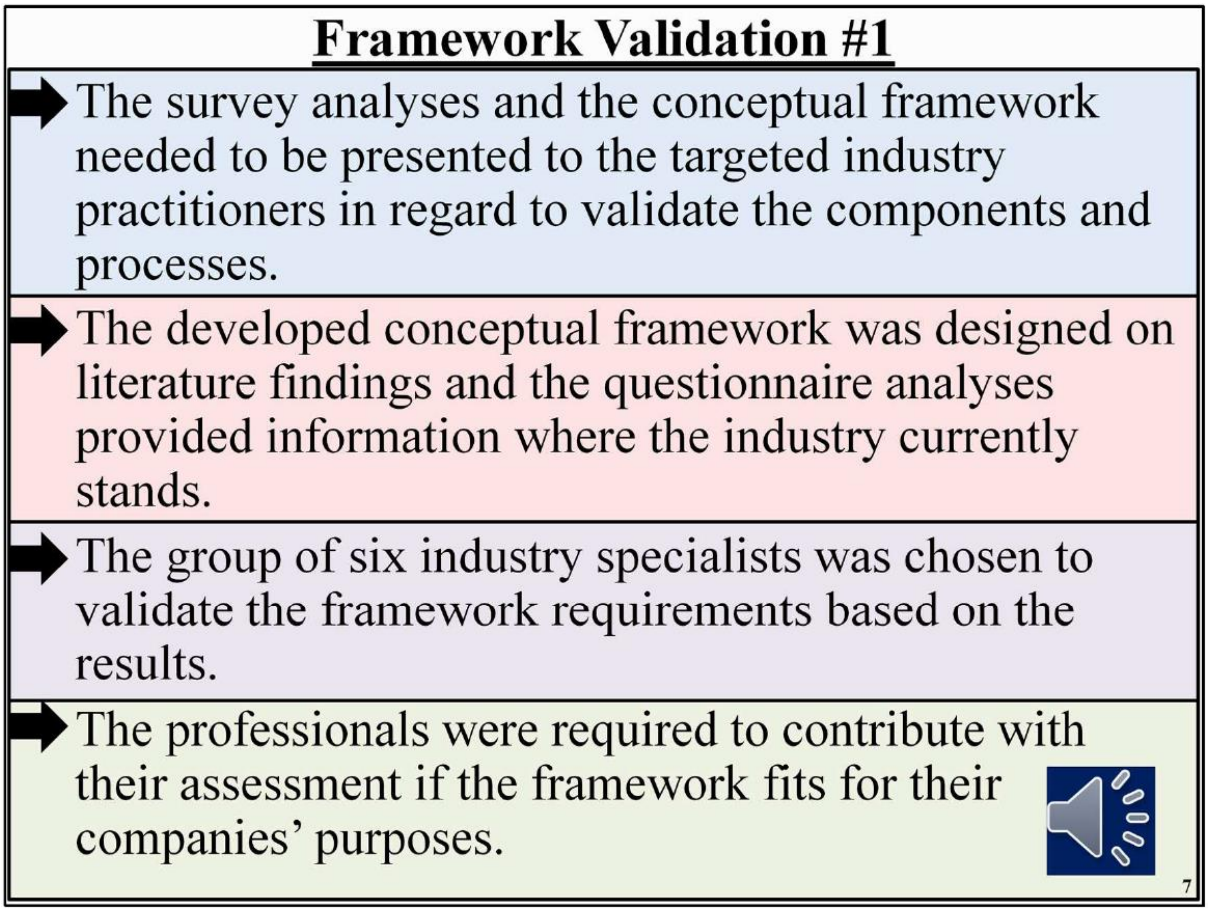
"Built on the literature findings a framework is proposed to provide an approach to specify the LOD during the planning process and subsequently allow multi LOD simulations to be developed within the 4D session. It is anticipated that the application of this framework would improve current planning practices by allowing appropriate, visual planning through in-built communication within a building information model. Furthermore, more dynamic 4D model would promote and enable more collaborative and coordinated construction planning."



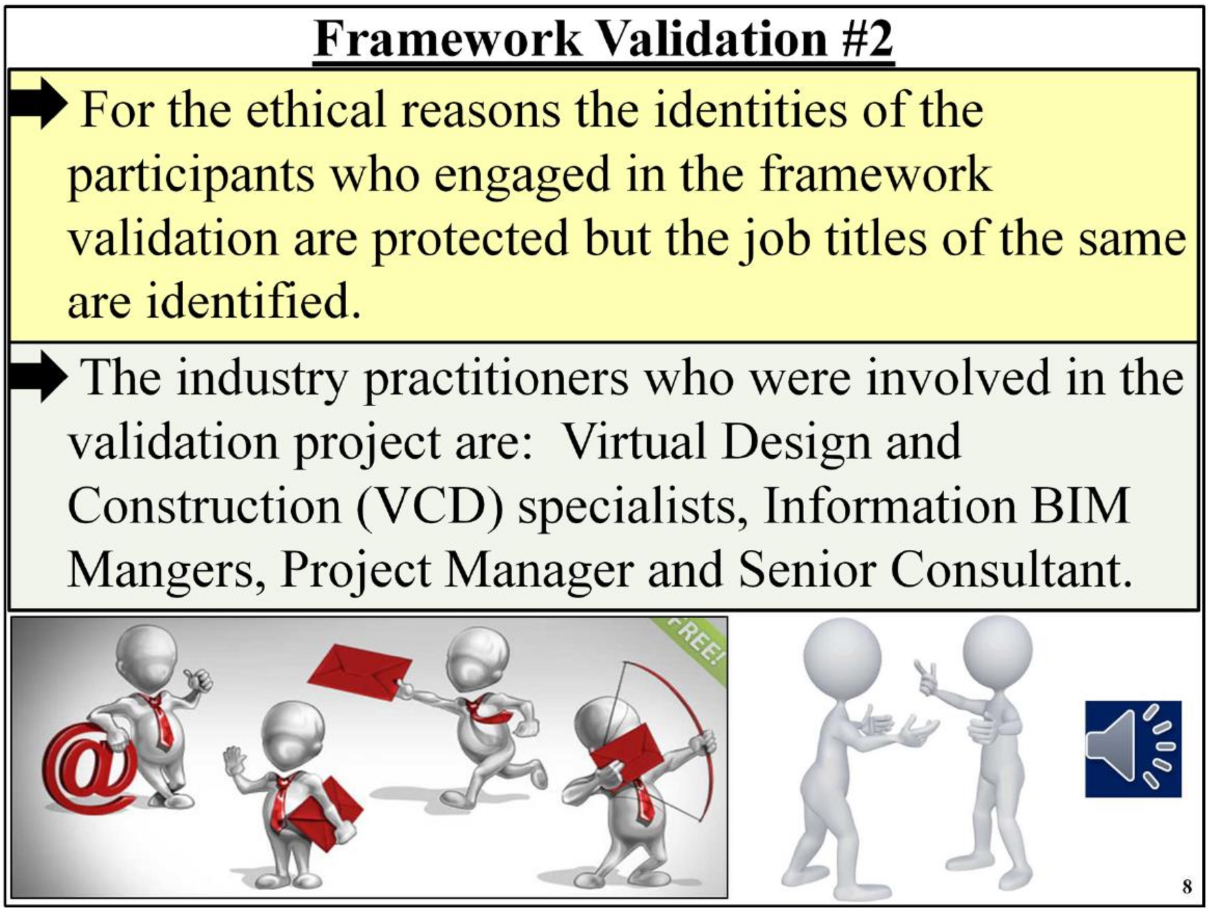
"An online questionnaire was developed targeting population of the study who actively engaged in using 4D simulations on a range of construction projects across a section of companies identified from industry. A total sample size of 101 questionnaires were issued with 82 responses being received. Of these responses a total of 61 fully completed questionnaires were received, response rate of 60%, and treated as valid for the purposes of the analysis."



"Example Tasks. The record indicated that the majority of respondents are in opinion that only on Daily basis, the model should show changes, followed by Weekly with much lower values. However, Q24 (25) shows Landscaping Weekly is 36.1% higher than Daily is 29.5%."



"The developed conceptual framework was designed on literature findings and the questionnaire analyses provided information for improving the framework design for LOD of 4D simulation. However, it was considered crucial to verify if the requirements identified are accurate and inclusive. The group of six industry specialists was chosen to validate the framework requirements. The framework validly confirms the credibility and the strengths of a research study. Semi-structured interviews were conducted with actors involved in framework validation and all interviews were performed over Skype or LinkedIn via live text chat."



"The respondents agreed overall that the framework in general is valid and applicable to all construction projects where BIM is mandated. According to interviewees the framework takes in account the 4D imputes necessary to design the suitable process. In their opinion the level of effort to implement the framework would be insignificant in all BIM mandated projects, as many of the framework concepts already exist, and they all agree that the necessary components are included."

Analyses of the Framework Validation Interviews #1

Questions	Responses	Key findings from the validation (common themes)
Do you think that the framework as presented accurately addresses the needs of your company?	➢ *To a large extent yes.* ➢ *Yes. It takes into account the 4D inputs necessary to design a suitable process.* ➢ *I think it is a good start.* ➢ *Actually, for a good number of our clients, this is all they need.* ➢ *I would say "yes".*	Majority of respondents confirms that presented framework can address accurately the needs of companies where they work.
If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?	➢ *The level of effort to implement the framework would be minimal.* ➢ *Very little effort, as many of the framework concepts, already exist and are established implemented (where they are implemented).* ➢ *If you are saying all this will be set as mandatory and international or national standards will set the effort / granularity, then it could be quite involved.*	If the AEC industry were to implement the framework as designed, they would require minimal effort to do so on all BIM mandated projects.

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"Analyses of the Framework Validation Interviews. However, for the companies who are not BIM ready or at lower levels of implementation the effort would be significantly larger, this is due to the fact that AEC industry is not BIM matured evenly."

Analyses of the Framework Validation Interviews #2

Questions	Responses	Key findings from the validation (common themes)
Where do you think the level of detail in the 4D simulation should be specified?	➢ *In the EIR (Employers Information Requirements)* ➢ *In the BIM Execution Plan and maybe at high level in the EIR* ➢ *In Contract Specs or BIM execution plan.* ➢ *In an Employers Information Requirements for a BIM project.*	In EIR (Employers Information Requirements) & in BIM Execution Plan
How relevant do you think this approach would be to a typical construction project?	➢ *Very relevant* ➢ *The framework will be relevant for ANY project using BIM, some industries will see larger relevance (and benefit) - for example, buildings, single location projects.* ➢ *Very relevant assuming the project had a reasonable complexity.*	Relevance of the framework approach in construction projects was confirmed by all interview participants.

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"The respondents suggested the use of framework on 4D construction project in planning and scheduling by specifying 4D requirements clearer and processing inputs and outputs in Employers Information Requirements and verify responsibilities and roles in 4D modelling."

Analyses of the Framework Validation Interviews #3

Questions	Responses	Key findings from the validation (common themes)
How might you use that framework on a construction project where you need 4D?	➢ *We are almost following the same framework. We do design the 4D in the same lines.* ➢ *To help ensure the 4D requirements are considered.* ➢ *As a method of helping a team de-mystify how 4D should fit in to the bigger picture BIM delivery.* ➢ *Your framework determines the LOD combination that gives highest ROI (return of Investment) then you follow the rest of the framework.* ➢ *I would use it to change the methods of planning and scheduling and specify the requirement for 4D more clearly, to gain measurable benefits.*	The framework suggested could be used on 4D construction projects to change the methods of planning and scheduling by specifying 4D requirements clearer and processing inputs and outputs in EIRs and verify responsibilities and roles in 4D modelling.
How might you improve the framework?	➢ *By putting comparability between the software.* ➢ *Consider CBS (cost breakdown structure) and risk* ➢ *An LOD can be referenced for model LOD.* ➢ *I think showing it as an input - process - output model showing the level of maturity in projects against it. Adding logistic pathways and cost level of information to the graphical may help clarify the inputs better.*	Potential needs to include CBS (cost breakdown structure) and high-level guideline to address various LODs in a 4D schedule.

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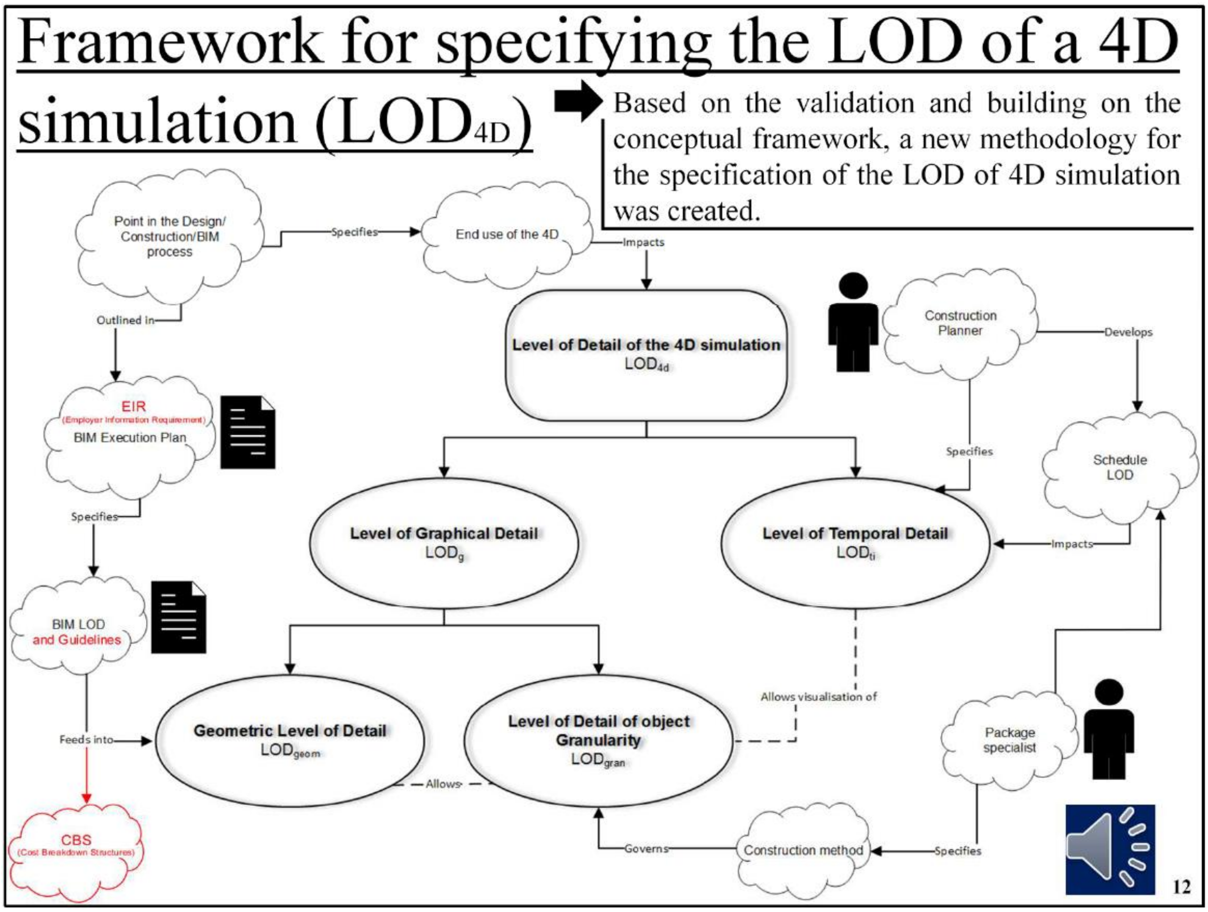
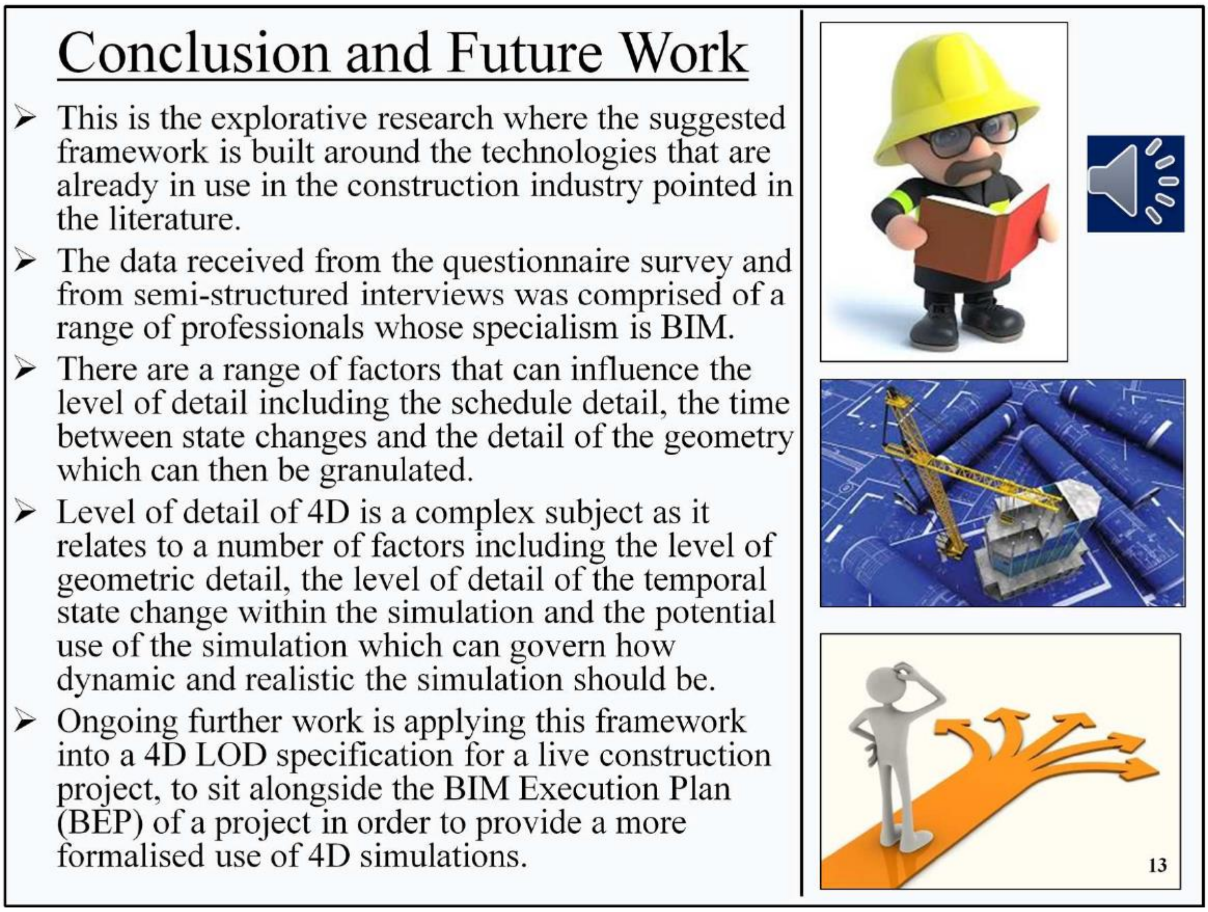
"They also suggested the inclusion of cost breakdown structure in innovative 4D framework."



"The research indicates that the framework as created could be beneficial to the industry, as the framework addresses the current industry needs to a high degree. Nevertheless, the findings from the literature, the results of the main survey and the interview results initiated further updates of the framework. The framework should assume automation of progress monitoring supports. However, currently some 4D software incorporates tools providing decomposition of geometric objects within the produced environment, by permitting the subdivision of geometry; although this is still a very manual exercise and not dynamically linked to the specification of a temporal level of detail."



"The research study was set out to explore the impact of the level of detail in the 4D technology and the issues of communication and collaboration, in order to offer most appropriate framework for more dynamic and more realistic 4D simulation. The research questions were answered by employing a mixed method strategy with a combination of online questionnaire and the live text interviews through Skype and LinkedIn social media. All the pragmatic findings were considered and allowed the researcher to gain an insight into professionals' experiences. Regardless of whether that perception has been achieved, this study has tried to understand the range of the existing body of knowledge, and then to contribute in a meaningful way."

References

- Akbas, R., and Fischer, M. (2002) *Construction Zone Generation Mechanisms and Applications*, ISARC 2002, 19th International Symposium on Automation and Robotics in Construction, Sep. 23-25, 2002, Washington DC, USA, NIST SP 989, William C. Stone, editor, pp. 293-298
- Butkovic, B and Heesom, D. (2017) Towards A Framework For Multi-LOD 4D BIM Simulations. *International Research Conference 2017*. University of Salford, 11-12 September, pp. 578-586
- Heesom, D. and Mahdjoubi, L. (2003) A Dynamic VR System For Visualizing Construction Space Usage. ASCE Construction Research Congress, Winds of Change: Integration and Innovation of Construction. Eds Molenaar, K. and Chinowsky, P. Honolulu, Hawaii. March 19-21 2003. ISBN: 0-7844-0671-5
- Han, K.K. and Golparvar-Fard, M. (2015) Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs, *Automation in Construction*, **53**, pp.44-57
- Tolmer, C.E., Castaing, C., Morand, D. and Diab, Y. (2015) Information management for linear infrastructure projects: conceptual model integrating Level of Detail and Level of Development: *Proc. of the 32nd CIB W78 Conference*. University of Technology, Eindhoven 27-29 October. Rotterdam: International Council for Research and Innovation in Building and Construction, pp.735-743
- Winch, G.M. (2010) *Managing Construction Projects.* 2nd ed. West Sussex: Wiley

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- **Publication titled:** "*The Need for Multi-LOD 4D Simulations in Construction Projects*" and the paper submitted in August 2018 for ITcon journal and waiting for reviewers.

14

The End

Thank you for your attention!

You can email me.

Email address is b.butkovic@wlv.ac.uk

Bogdan Butkovic - PhD Candidate

Any Question?

15

Appendix C: Posters

Impact Of 4D LOD (Level of Detail) on Communication In Construction Projects

Annual review meeting in May 2016

Towards A Framework For Multi-LOD 4D BIM Simulations

Annual review meeting in May 2017

Towards A Framework For Multi-LOD 4D BIM Simulations

Judging criteria for poster competition in June 2018

Understanding The Need For Multi-LOD 4D Simulations In Construction Projects

Annual review meeting in June 2018

Impact of 4D LOD (Level of Detail) on Communication in Construction Projects

Abstract

The latest existing technology has many effects and benefits in construction projects. The success of Building Information Modelling (BIM) lies in enhancing the collaborative process of design and engineering. The contribution of the design and constructions are provided with an integrated database of coordinated information.

BIM provides work within a coordinated, 3D model-based environment that automatically updates designs when changes are made. Adding a 4th dimension allows the schedule to be linked with data objects at an appropriate level of detail. The project is then built visually testing different options. This gives the opportunity to try many options before deciding on the best one (Eastman et al., 2011). The 4D model simulation addresses the issue of construction operations by providing views of activities during any period of construction.

However, as a 4D model integrates 3D building models with time, a 3D BIM model mainly provides information regarding 3D components, and there are few advantages over 3D models used in 4D applications.

Background

3D digital models are assembled in the same way a building is constructed The 3D models linked to time parameters and designed four dimensional (4D) models (Fischer and Kunz, 2004) . A 4D model improves construction projects by providing better communications among project parties (Leinonen et al., 2003) as well as improving the design, coordination, and construction process. 4D CAD helps different project contributors to understand and comment on the project options in a practical and well-timed manner. 4D models allow the consideration in advance of the effectiveness of the project approach, progression in the constructability with consistent improvements in on-site efficiency, and the shift documentation and resolution of time-space clashes.

For the performance of construction projects, information flow is critical in construction management. The project flow starts with the project planning with clearly identified roles for project participants and understanding of their responsibilities in the project and importance of information flow throughout the entire project (Hardin, 2015).

Increasing interest in the collaborative use of 4D modelling and simulation enhances the importance of the Level of Detail (LOD) of the model. LOD is basically how much detail in included in the model element. The LOD model is affected by the time planned to build it and the size of the model and these important items need to be communicated (Kensek, 2014).

Communication between numerous participants is essential on collaborative projects, because the various design stages of the architectural process involve the collaboration of many disciplines. The design information that is generated in the early stages of a construction project is utilized and modified in the follow up stages (Choi, 2014).

Research problem

Even though 4D modelling has been recognized as technology with clear advantages during the design and construction process, this technology lacks the construction plan information as the construction activities could not all be visually presented. There is also no clear evaluation and duration of activities in the project. The 4D model is a static image therefore a 4D simulation lacks dynamics in order to achieve more reliable outcomes. Absence of appropriate levels of detail in a 4D model, which would start with the project planning, would provide more realistic simulation and more accurate results.

The Level of Development

It grows over time to progress from **LOD 100 to LOD 500** (BIMForum, 2013):

- **LOD 100: Conceptual mass –** The Model fragment can be realistically represented in the model using a symbol or other realistic representation.
- **LOD 200: Model masses –** The Model Element is graphically represented as a stranded system, item or assembly with proper size, quantities, shape, orientation and location within the Model.
- **LOD 300: Model materials with assemblies –** The Model Element graphically represented as a detailed system, object or assembly regarding the size, shape, quantity, orientation and location within the model.
- **LOD 400: Construction detailed –** The Model includes the shape, location, quantity and orientation, text dimensions notes and 2D details.
- **LOD 500:** The Model Element here is a field verified representation and constructed model suitable for operations and maintenance).

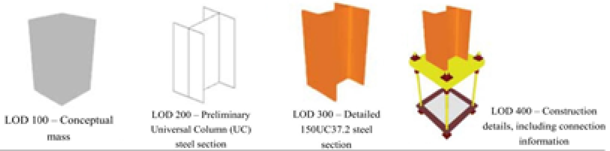

Figure 1: LOD progression of a steel column section (Wood, 2014)

Figure 2: The LOD Experiment (Hooper, 2015)

Aim

Based on the foregoing, the aim of this project is the development of a Level of Detail (LOD) framework for a 4D BIM to enhance communication at various stages of the construction process.

Objectives

The study objectives are:

- A critical review of prevailing literature in the field of BIM and 4D modelling.
- Investigating the value of current 4D modelling tools used for schedule visualization in construction engineering.
- Analysing the activity sequencing and findings incorporated in the research and the effect of communication between the design and construction team in the real-life construction project (UoW).
- Developing the framework.

Anticipated results

The current research lacks a detailed and deep study of LOD at the organization level during the visualization process within the 4D simulation. The limited research in addressing this issue in design and construction creates the need for the development and implementation of such a framework in the selected business unit.

Based on the value of current 4D modelling tools used for the schedule visualization in the AEC industry, the research was undertaken in the project site considering the existing communication between project parties in order to develop a sufficient level of detail in the framework.

References

Anon (2013) *Level of Development Specification – BIMForum PDF* [online]. [Accessed 7 November 2015]. Available at <http://bimforum.org/wp-content/uploads/2013/08/2013-LOD-Specification.pdf>

Choi, J., Choi, J. and Kim, I. (2014) Development of BIM-based evacuation regulation checking system for high-rise and complex buildings, *Automation in Construction*, **46**, pp.38-49

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2011) *BIM Handbook – A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers, and Constructors*. 2nd ed. New Jersey: Wiley

Fischer, M. and Kunz, J. (2004) *The Scope and Role of Information Technology in Construction – Stanford University PDF* [online]. [Accessed 25 June 2015]. Available at <http://cife.stanford.edu/sites/default/files/TR156.pdf>

Harden, B. and McCool, D. (2015) *BIM and Construction Management* [online]. Indianapolis: Wiley. [Accessed 10 October 2015]. Available at: <https://www.dawsonera.com/>

Hooper, M. (2015) Automated model progression scheduling using level of development, *Construction Innovation*, **15**(4), pp.428-448

Leinonen, V., Kankaanpaa, M., Luukkonen, M., Kansanen, M., Hanninen, O., Airaksinen, O., and Taimela, S. (2003) Lumbar paraspinal muscle function, perception of lumbar position, and postural control disc herniation-related back pain, *Spine*, **28**, pp.842-848

Kensek, M.K. and Noble, D. (2014) *Building Information Modeling – BIM in Current and Future Practice* [online]. Hoboken: Wiley. [Accessed 14 February 2015]. Available at: <https://www.dawsonera.com/>

Wood, J., Panuwatwanich, K. and Doh, J. (2014) Using LOD in structural cost estimation during building design stage: Pilot Study, *Procedia Engineering*, **85**, pp.543-552

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Faculty of Science and Engineering

Author: Bogdan Butkovic PhD candidate

Supervisors: Dr. David Heesom and Mr. Chris Williams

TOWARDS A FRAMEWORK TO MULTI-LOD 4D SIMULATIONS

Background

3D digital models are assembled in the same way a building is constructed. 3D models can be linked to time parameters and designed as four dimensional (4D) models (Fischer and Kunz, 2004). A 4D model improves construction projects by providing better communications among project parties (Leinonen *et al.*, 2003) as well as improving the design, coordination, and construction process. 4D CAD helps different project contributors to understand and comment on the project options in a practical and well-timed manner. 4D models allow advance consideration of the effectiveness of the project approach, the construction progress, with consistent improvements in on-site efficiency, and the shift documentation and resolution of time-space clashes.

For the performance of construction projects, information flow is critical in construction management. The project flow starts with the project planning, with clearly identified roles for project participants and their respective responsibilities in the project, and the importance of information flow throughout the entire project (Hardin and McCool, 2015).

Increasing interest in the collaborative use of 4D modelling and simulation enhances the importance of the Level of Detail (LOD) of the model. LOD is basically how much detail in included in the model element. The LOD model is affected by the time planned to build it and the size of the model and these important items need to be communicated (Kensek and Noble, 2014).

Communication between numerous participants is essential on collaborative projects, because the various design stages of the architectural process involve the collaboration of many disciplines. The design information that is generated in the early stages of a construction project is utilized and modified in the follow up stages (Choi *et al.*, 2014).

Aim

Based on the foregoing, the aim of this project is the development of a Level of Detail (LOD) framework for a 4D BIM to enhance communication at various stages of the construction process.

Objectives

The study objectives are:

- A critical review of prevailing literature in the field of BIM and 4D modelling.
- Investigating the value of current 4D modelling tools used for schedule visualization in construction engineering.
- Analysing the activity sequencing and findings incorporated in the research and the effect of communication between the design and construction team in the real-life construction project (UoW).
- Developing the framework.

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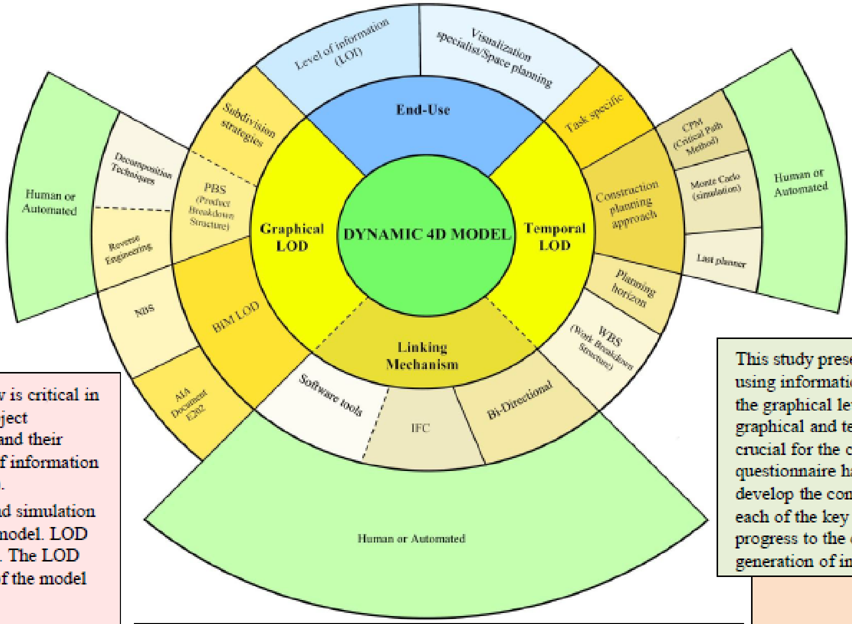

Figure 1: Conceptual framework of Dynamo 4D model

The Level of Development

It grows over time to progress from **LOD 100 to LOD 500** (BIMForum, 2013):

- **LOD 100: Conceptual mass** – The Model fragment can be realistically represented in the model using a symbol or other realistic representation.
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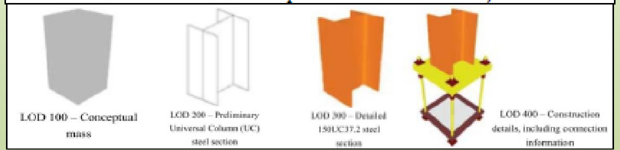

Figure 2: LOD progression of a steel column section (Wood *et al.*, 2014)

The anticipated framework attempts to focus on the key issues identified in the literature. This conceptual framework is a set to address problems acknowledged within the current construction planning practice and the drawbacks and the future capabilities of 4D methodologies through the application of new technological solutions, directed towards a strong and innovative approach to the construction plan creation.

It is anticipated that the application of this framework would improve current planning practices by allowing appropriate, visual planning through in-built communication within a building information model. Furthermore, more dynamic 4D modelling would promote and enable more collaborative and coordinated construction planning.

This study presents a framework for creating a more dynamic 4D model by using information from BIM. The critical parts of the conceptual framework are the graphical level of detail and various levels of temporal detail. Both graphical and temporal levels of detail are influenced by numerous factors crucial for the construction project. At the current stage of this research a questionnaire has been developed for data collection, in order to further develop the conceptual framework and assess the industry requirements for each of the key attributes. Based on the information obtained, the research will progress to the development of prototype software tools that will allow the generation of interactive dynamic 4D simulations at multiple levels of detail.

Research problem

Even though 4D modelling has been recognized as technology with clear advantages during the design and construction process, this technology lacks the construction plan information as the construction activities could not all be visually represented. There is also no clear evaluation and duration of activities in the project. The 4D model is a static image therefore a 4D simulation lacks dynamics in order to achieve more reliable outcomes. Absence of appropriate levels of detail in a 4D model, which would start with the project planning, would provide more realistic simulation and more accurate results.

References

Anon (2013) *Level of Development Specification – BIMForum PDF* [online]. [Accessed 7 November 2015]. Available at <http://bimforum.org/wp-content/uploads/2013/08/2013-LOD-Specification.pdf>

Choi, J., Choi, J. and Kim, I. (2014) Development of BIM-based evacuation regulation checking system for high-rise and complex buildings. *Automation in Construction*, **46**, pp.38-49

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Author: Bogdan Butkovic PhD candidate

Supervisors: Dr. David Heesom and Mr. Chris Williams

Author:
BOGDAN BUTKOVIC
PhD Candidate (0908325)

TOWARDS A FRAMEWORK TO MULTI-LOD 4D SIMULATIONS

Supervisor:
Dr. David Heesom

ABSTRACT

3D digital models are assembled in the same way a building is constructed. The 3D models linked to time parameters and design four dimensional (4D) models. A 4D model improves construction projects by providing better communications among project parties as well as improving the design, coordination, and construction process. For the performance of construction projects, information flow is critical in construction management. The project flow starts with the project planning with clearly identified roles for project participants and understanding of their responsibilities in the project and importance of information flow throughout the entire project. Increasing interest in the collaborative use of 4D modelling and simulation enhances the importance of the Level of Detail (LOD) of the model. LOD is basically how much detail is included in the model element. The LOD model is affected by the time planned to build it and the size of the model and these important items need to be communicated. Communication between numerous participants is essential on collaborative projects, because the various design stages of the architectural process involve the collaboration of many disciplines. The conceptual framework is set to address problems acknowledged within the current construction planning practice and the drawbacks and the future capabilities of 4D methodologies through the application of new technological solutions. It is anticipated that the application of this framework would improve current planning practices by allowing appropriate, visual planning through in-built communication within a building information model.

AIM AND OBJECTIVES

Based on the foregoing, the **aim** of this project is the development of a Level of Detail (LOD) framework for a 4D BIM to enhance communication at various stages of the construction process.

The study **objectives** are:

- A critical review of prevailing literature in the field of BIM and 4D modelling.
- Investigating the value of current 4D modelling tools used for schedule visualization in construction engineering.
- Analysing the activity sequencing and findings incorporated in the research and the effect of communication between the design and construction team in the real-life construction (UoW).
- Developing the framework.
- Validating the framework.

FRAMEWORK DEVELOPMENT

- Improvement of current planning practices by allowing appropriate, visual planning through in built communication within a building information model.
- More dynamic 4D modelling which would promote and enable more collaborative and coordinated construction planning.

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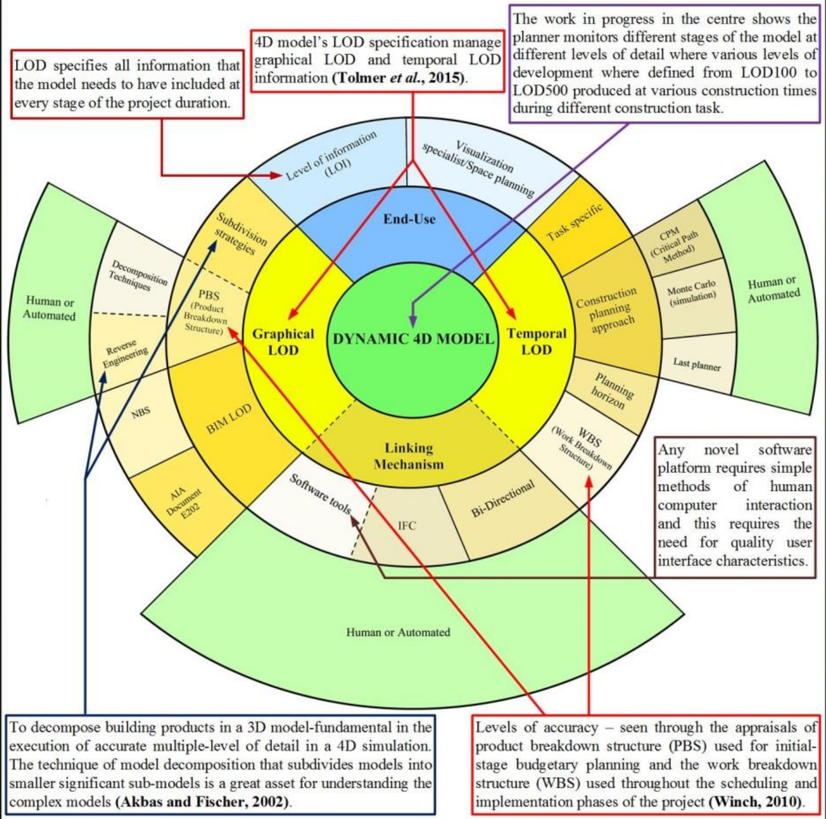
CONCEPTUAL FRAMEWORK OF DYNAMIC 4D MODEL (D4DM)

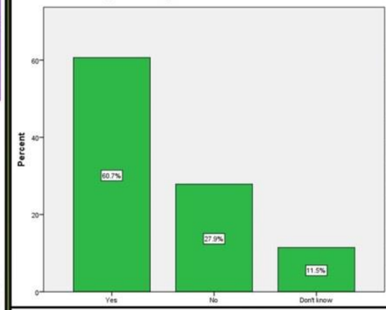


EXECUTED WORK

- Based on the subject of a framework for multi-LOD 4D BIM simulations the research paper was published in order to introduce the proposed framework.
- The industry based questionnaire was developed and sent out by the email using a link to the online account.
- The survey was divided into four sections of information (personal, company, Dynamic 4D model and examples tasks) in order to generate data concerning various companies which currently use BIM and their involvement in the construction industry.
- It was anticipated that the results were compared with the results from the literature review findings.

RESULTS OF THE STUDY

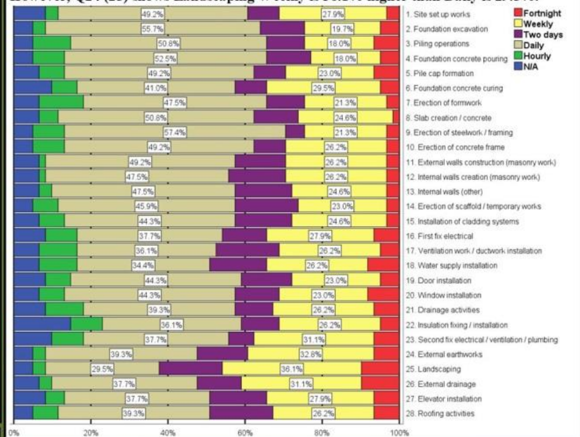
One of the most significant question of the questionnaire was: Do you think you should have the ability to change the detail of the 4D model directly within the 4D software tool?



The majority of respondents 60.7% are in the opinion of needs to have the ability to change the detail of the 4D model within the 4D software, followed by 27.9% of respondents who disagree and 11.5% of these who do not know. The majority of respondents believe, with a 4D model that shows more details the time period between model changes can be shorten e.g. less than current weekly bases, the system would improve the identification of potential conflicts and clashes.

EXAMPLE TASKS

The record indicated that the majority of respondents are in opinion that only on Daily basis, the model should show changes, followed by Weekly with much lower values. However, Q24 (25) shows Landscaping Weekly is 36.1% higher than Daily is 29.5%.



FUTURE WORK

- The survey results will help in further development of the concrete framework.
- The framework should provide information to improve established software.
- Following to this consideration of most appropriate software tools will be undertaken to progress the development of a prototype software tool that will allow the generation of interactive dynamic 4D simulations at multi levels of detail.

REFERENCES

Akbas, R. and **Fischer**, M. **(2002)** *Construction Zone Generation Mechanisms and Applications*, ISARC 2002, 19th International Symposium on Automation and Robotics in Construction, Sep. 23-25, 2002, Washington DC, USA, NIST SP 989, William C. Stone, editor, pp. 293-298.

Tolmer, C.E., Castaing, C., Morand, D. and Diab, Y. **(2015)** Information management for linear infrastructure projects: conceptual model integrating Level of Detail and Level of Development: *Proc. of the 32nd CIB W78 Conference*. University of Technology, Eindhoven 27-29 October. Rotterdam: International Council for Research and Innovation in Building and Construction, pp.735-743

Winch, G.M. **(2010)** *Managing Construction Projects*. 2nd ed. West Sussex: Wiley

UNDERSTANDING THE NEED FOR MULTI-LOD 4D SIMULATIONS IN CONSTRUCTION PROJECTS

ABSTRACT

Although 4D technology has facilitated entire new level of collaboration through the use of BIM tools, the industry still has to succeed in common understandings of BIM concepts and applying reliable methodologies that may support significant improvement of digital information over time, through construction project phases. It has been acknowledged the benefit of 4D models in planning phase in order to avoid foreseen conflicts during the construction. However, the static image of 4D simulation and absence of more reliable outcomes are the technologies' drawbacks. Level of detail (LOD) has been seen as important instrument for indicating information exchange during the course of a facility' life cycle. The research has been led with intention to create the suitable framework for more dynamic 4D model. The survey was conducted to assess the use of 4D BIM technology and the understanding of importance of levels of graphical and temporal details and how to improve the 4D visualization dynamics. The overall conclusions of research indicate that: A) if a 4D model shows more details it can improve the identification of potential conflicts and clashes in work process. B) the need for ability to change the details of the 4D directly within the software and C) that 4D Model needs to be updated every day.

AIM AND OBJECTIVES

Based on the foregoing, the **aim** of this project is the development of a Level of Detail (LOD) framework for a 4D BIM to enhance communication at various stages of the construction process.

The study **objectives** are:

- A critical review of prevailing literature in the field of BIM and 4D modelling.
- Investigating the value of current 4D modelling tools used for schedule visualization in construction engineering.
- Analysing the activity sequencing and findings incorporated in the research and the effect of communication between the design and construction team in the real-life construction (UoW).
- Developing the framework.
- Validating the framework.

FRAMEWORK DEVELOPMENT

- Improvement of current planning practices by allowing appropriate, visual planning through in built communication within a building information model.
- More dynamic 4D modelling which would promote and enable more collaborative and coordinated construction planning.

EXECUTED WORK

- Based on the subject of a framework for multi-LOD 4D BIM simulations the research paper was published in order to introduce the proposed framework.
- The industry based questionnaire was developed and sent out by the email using a link to the online account.
- The survey was divided into four sections of information (personal, company, Dynamic 4D model and examples tasks) in order to generate data concerning various companies which currently use BIM and their involvement in the construction industry.
- It was anticipated that the results were compared with the results from the literature review findings.

RESULTS OF THE STUDY

Occupation role		Q1a: (Occupation role) Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Execution role: General	1	1.6	1.6	1.6
	Management role: CEO	5	8.2	8.2	9.8
	Project Manager	6	9.8	9.8	19.7
	Building Surveyor	1	1.6	1.6	21.3
	Main Contractor / Suppliers	1	1.6	1.6	23.0
	Software Programmer	3	4.9	4.9	27.9
	Planner	3	4.9	4.9	32.8
	Architect / Lead designer	6	9.8	9.8	42.6
	Information Manager	4	6.6	6.6	49.2
	BIM Manager / BIM Co-ordinator	22	36.1	36.1	85.2
	Cost consultant / quantity surveyor	1	1.6	1.6	86.9
	Civil Engineer	1	1.6	1.6	88.5
	Other	7	11.5	11.5	100.0
	Total	61	100.0	100.0	

Figure 1: Demographic Information: Occupation role

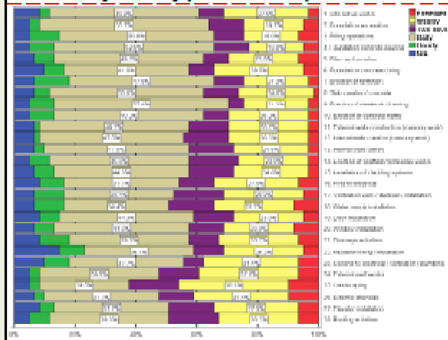


Figure 2: Example Tasks (1-28)

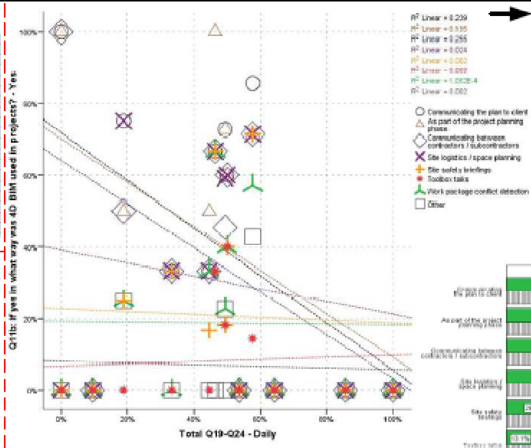


Figure 3: Established linear Q11 vs Total Q19-Q24 – Daily

Analyses revealed a negative coefficient of the regression line for site logistics/space planning (R^2 Linear = 0.0024), as shown in **Figure 3** (0.24%). The linear was established between the questions about the different use of 4D BIM in projects and the frequency of the task specific updates. Daily model update should be positive in order to keep better model information.

The record in **Figure 2** indicates that the majority of respondents are in opinion that only on Daily basis, the model should show changes, followed by Weekly with much lower values. However, Q24 (25) shows Landscaping Weekly is 36.1% higher than Daily is 29.5%.

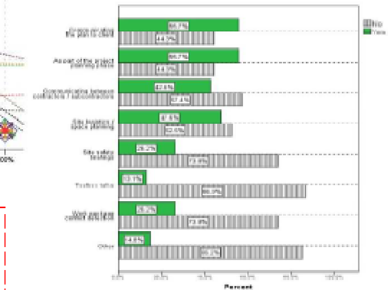


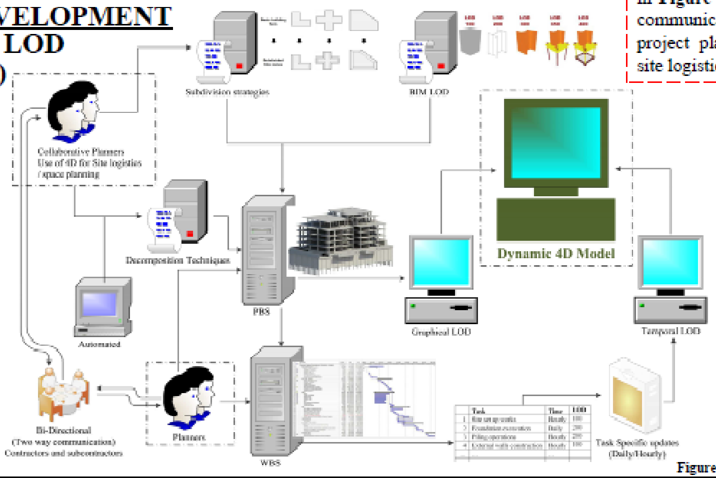
Figure 4: 4D BIM in the project are used (Q11b) showed in a transpose bar

The use of 4D BIM in the project is shown in **Figure 4**. The highest usage is for the communication with a client (55.7%), project planning phase (55.7%) and for site logistic/space planning (47.5%).

FRAMEWORK DEVELOPMENT FOR DYNAMIC 4D LOD (ONGOING WORK)

The survey results are crucial in further development of the concrete framework **(in Figure 5)**.

The information gains in the survey results indicate the importance of LOD in 4D simulations.



Following to this consideration of most appropriate software tools will be undertaken to progress the development of a prototype software tool that will allow the generation of interactive dynamic 4D simulations at multi-levels of detail.

Figure 5: Draft Framework for Dynamic 4D LOD

REFERENCES

Argyrous, G. (2011) *Statistics for Research: with A Guide To SPSS.* 3rd ed. London: Saga

Cooke, B. (2011) *Construction Practice.* Chichester: Wiley

Bryman, A. and Cramer, D. (2011) *Quantitative Data Analysis with IBM SPSS 17, 18 & 19.* Hove: Routledge

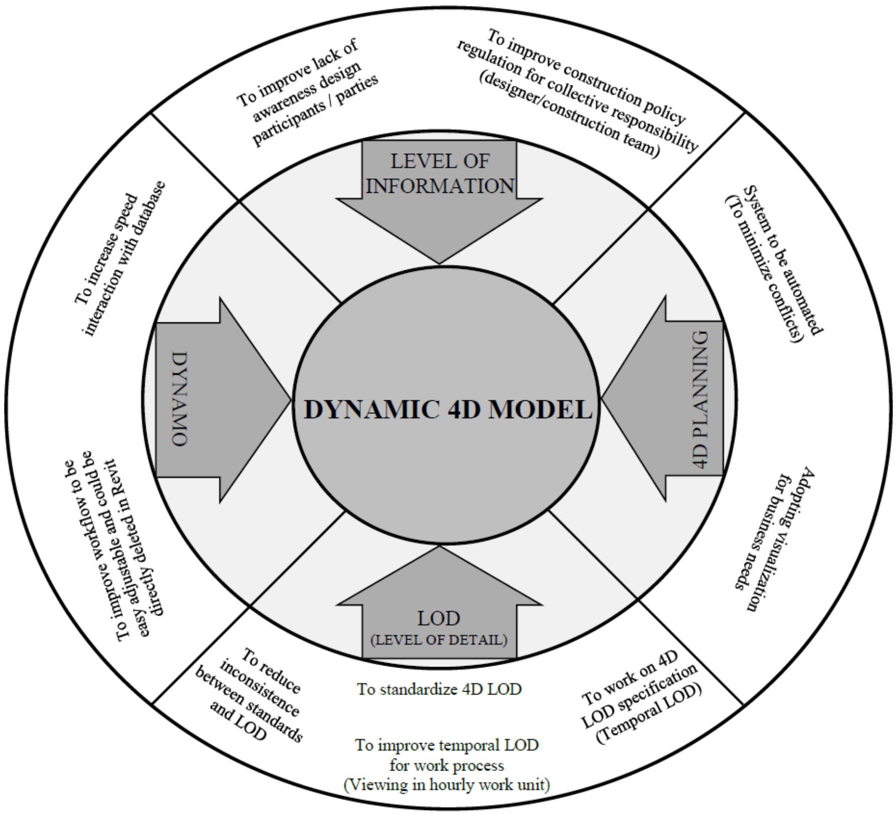
Gray, C.D. and Kinnear, P.R. (2012) *IBM SPSS 19 Made Simple.* Hove: Psychology Press

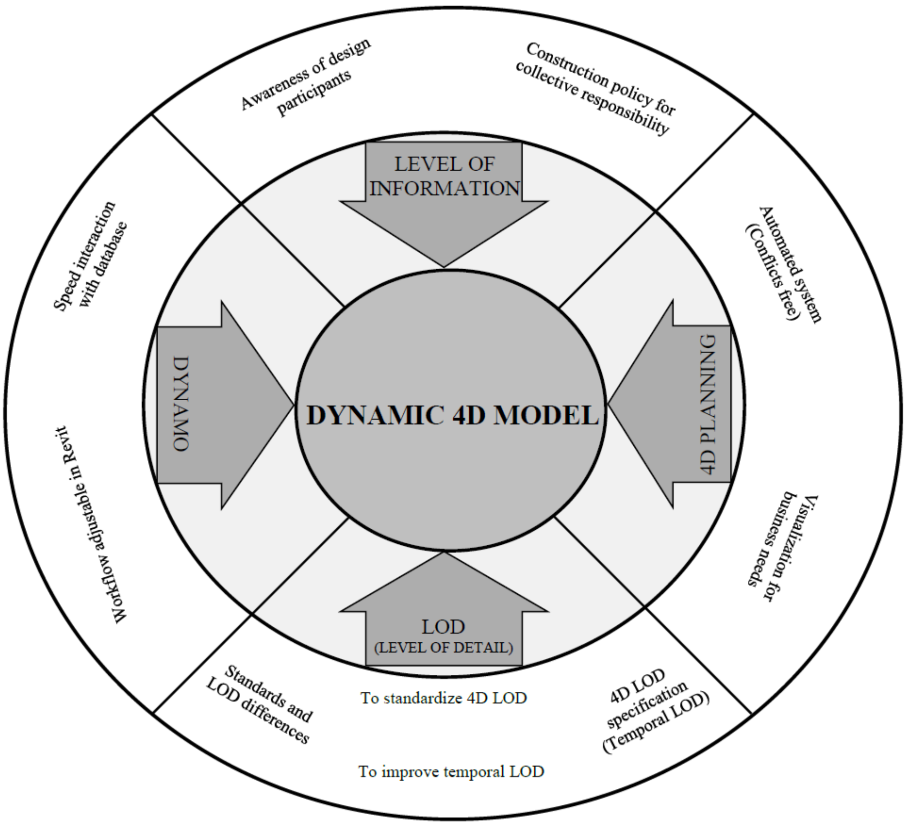
UNIVERSITY OF WOLVERHAMPTON
Faculty of Science and Engineering

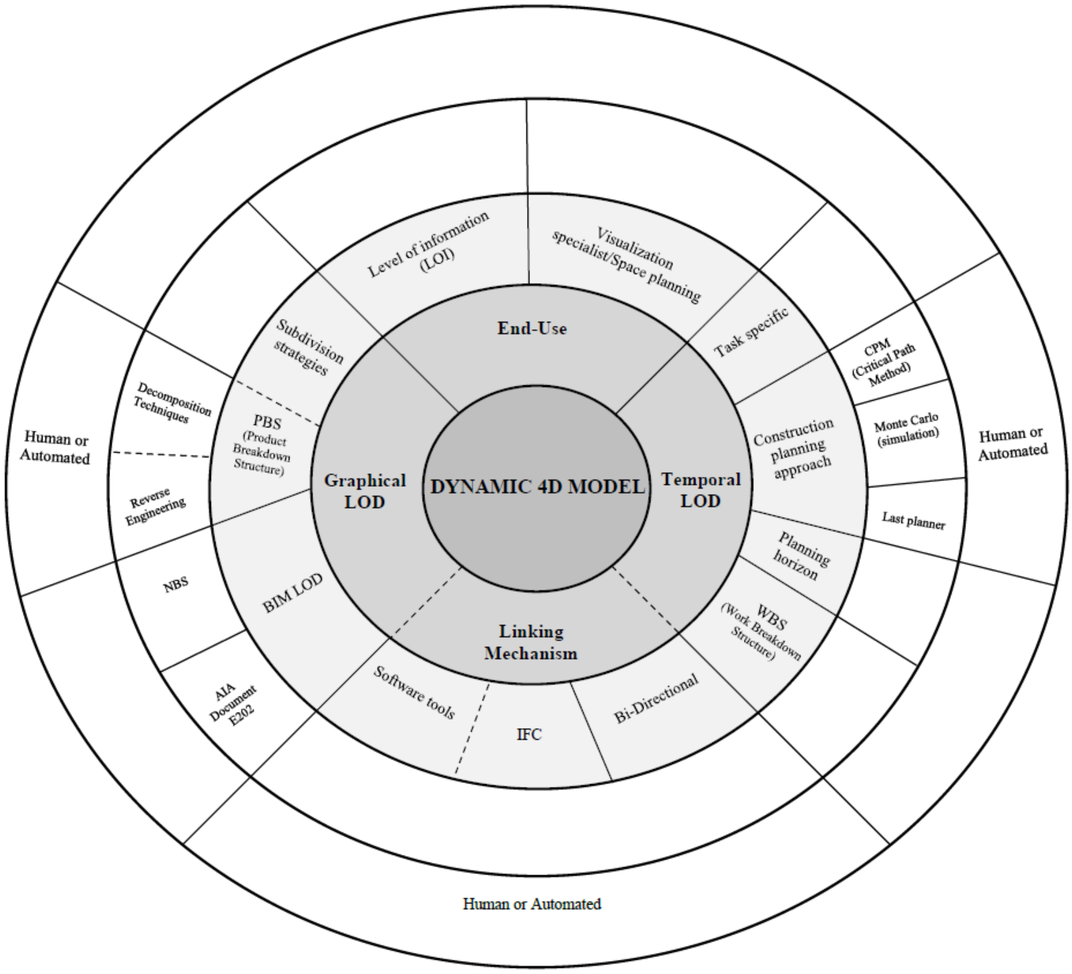
Author: BOGDAN BUTKOVIC, PhD Candidate (0908325)

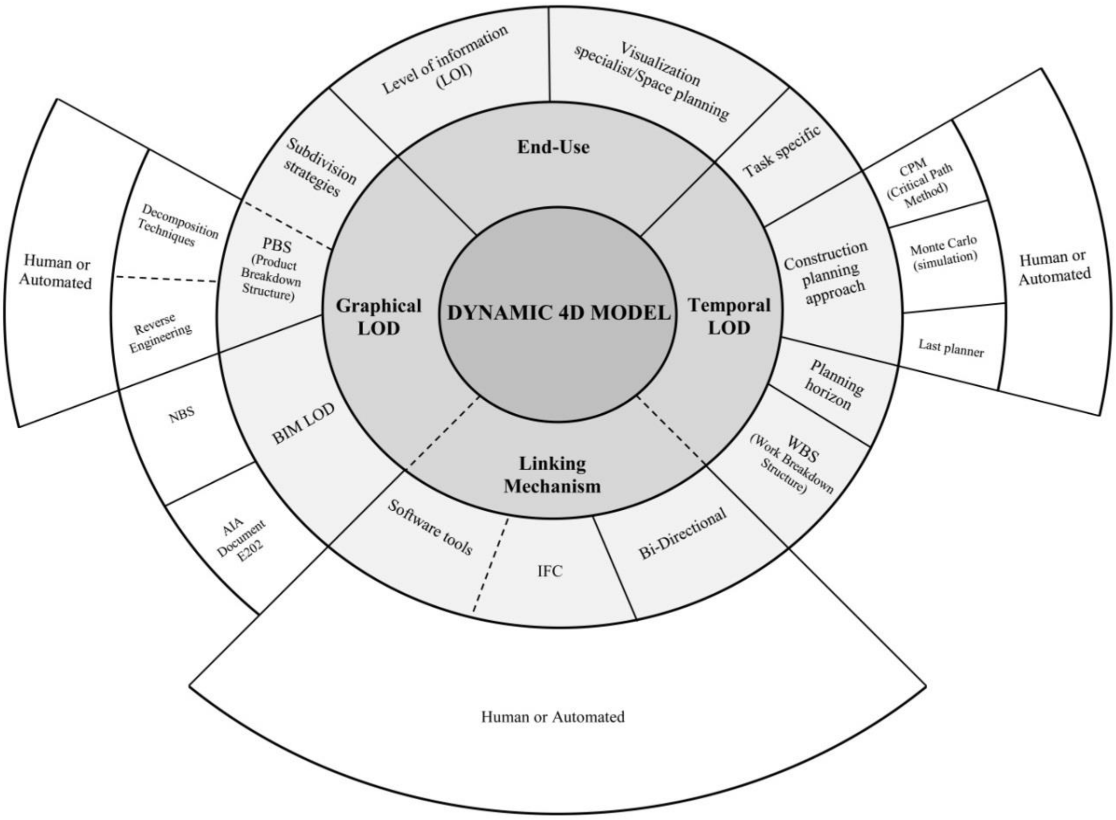
Supervisor: DR. DAVID HEESOM, Reader in BIM (Lecturer)

Appendix D: Framework processes






DYNAMIC 4D MODEL
End-Use
Graphical LOD
Temporal LOD
Linking Mechanism
Level of information (LOI)
Visualization specialist/Space planning
Task specific
Construction planning approach
Planning horizon
WBS (Work Breakdown Structure)
Bi-Directional
IFC
Software tools
BIM LOD
PBS (Product Breakdown Structure)
Subdivision strategies
Decomposition Techniques
Reverse Engineering
NBS
AIA Document E202
CPM (Critical Path Method)
Monte Carlo (simulation)
Last planner
Human or Automated
Human or Automated
Human or Automated


DYNAMIC 4D MODEL
End-Use
Graphical LOD
Temporal LOD
Linking Mechanism
Level of information (LOI)
Visualization specialist/Space planning
Task specific
Construction planning approach
Planning horizon
WBS (Work Breakdown Structure)
Bi-Directional
IFC
Software tools
BIM LOD
PBS (Product Breakdown Structure)
Subdivision strategies
Decomposition Techniques
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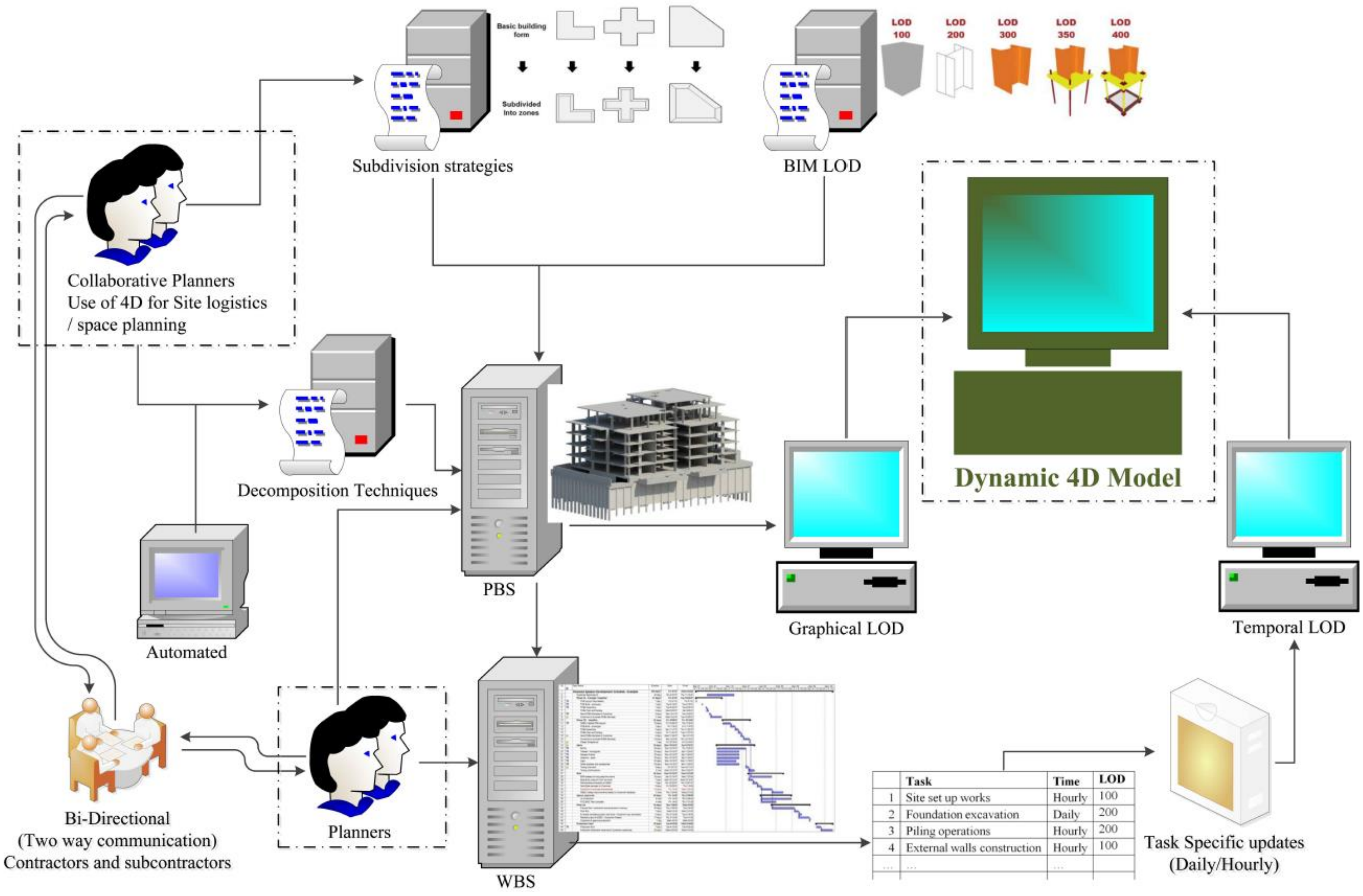
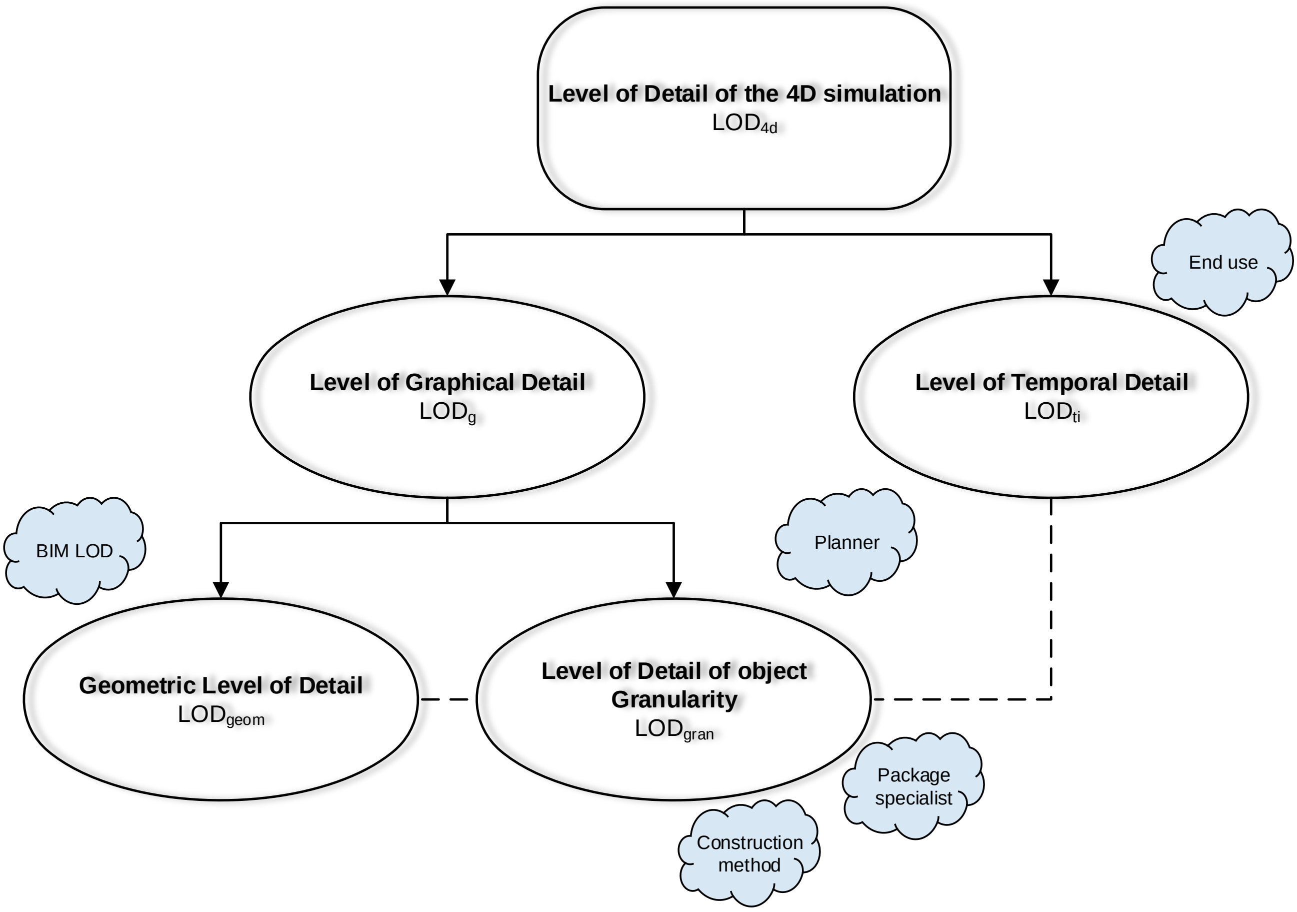
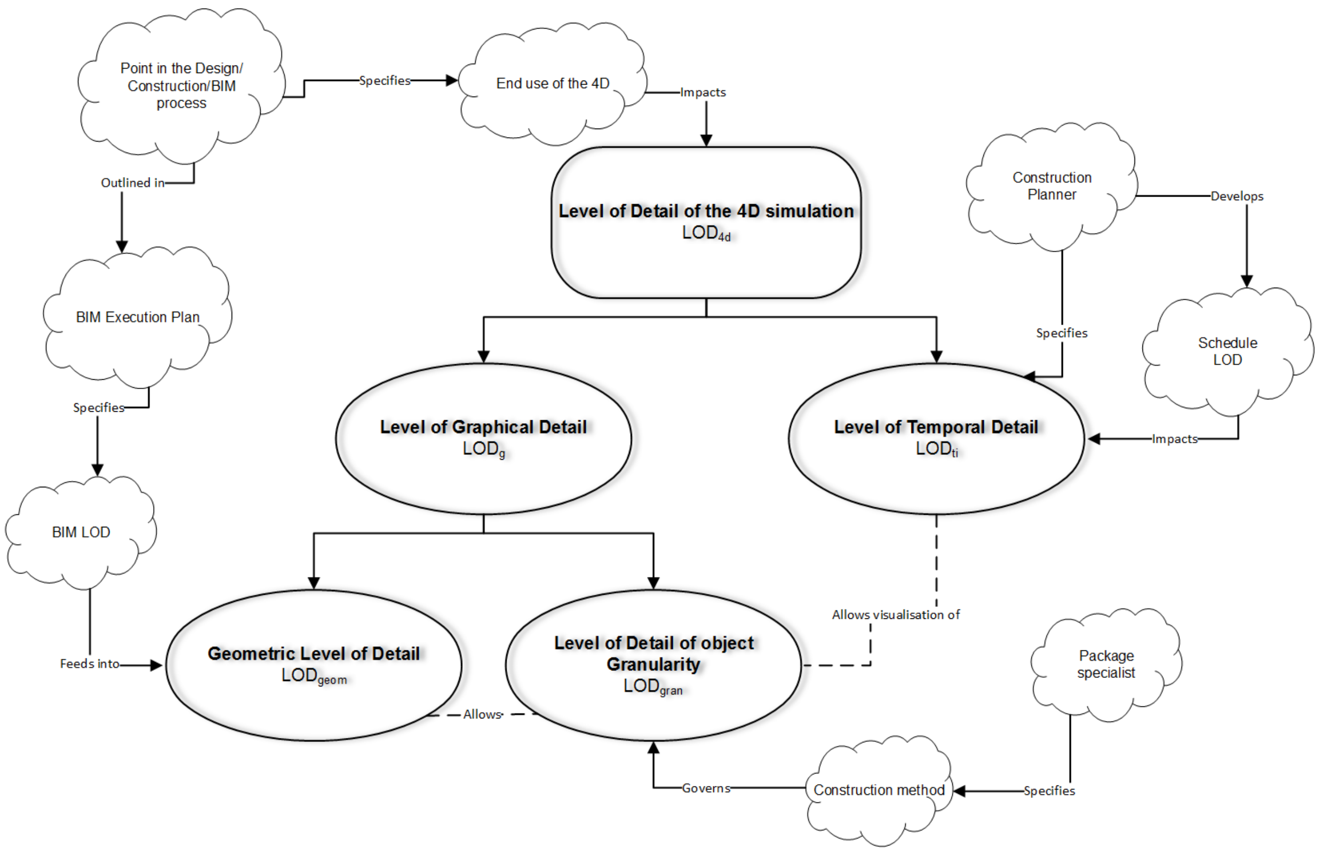
NBS
AIA Document E202
CPM (Critical Path Method)
Monte Carlo (simulation)
Last planner
Human or Automated
Human or Automated
Human or Automated


Basic building form
Subdivided into zones
Subdivision strategies
LOD 100
LOD 200
LOD 300
LOD 350
LOD 400
BIM LOD
Collaborative Planners
Use of 4D for Site logistics
/ space planning
Dynamic 4D Model
Decomposition Techniques
PBS
Graphical LOD
Temporal LOD
Automated
WBS
Bi-Directional
(Two way communication)
Contractors and subcontractors
Planners
Task | Time | LOD
1 | Site set up works | Hourly | 100
2 | Foundation excavation | Daily | 200
3 | Piling operations | Hourly | 200
4 | External walls construction | Hourly | 100
... | ... | ...
Task Specific updates
(Daily/Hourly)


Level of Detail of the 4D simulation
LOD4d
Level of Graphical Detail
LODg
Level of Temporal Detail
LODti
End use
BIM LOD
Planner
Geometric Level of Detail
LODgeom
Level of Detail of object Granularity
LODgran
Package specialist
Construction method


Point in the Design/ Construction/BIM process
Specifies
End use of the 4D
Impacts
Outlined in
Level of Detail of the 4D simulation
LOD4d
Construction Planner
Develops
BIM Execution Plan
Specifies
Schedule LOD
Specifies
Level of Graphical Detail
LODg
Level of Temporal Detail
LODti
Impacts
BIM LOD
Allows visualisation of
Feeds into
Geometric Level of Detail
LODgeom
Level of Detail of object Granularity
LODgran
Package specialist
Allows
Governs
Construction method
Specifies

Appendix E: Letters, Questionnaires, Contract Review, Responses and Grouped Occupation Roles

Date Letter: 11th December 2017

Dear Participant,

This research study is being conducted by Bogdan Butkovic – the PhD Candidate for Postgraduate Research in Built Environment, specializing on impact of 4D LOD at the University of Wolverhampton.

The purpose of the study is to identify the lack of awareness and potential needs for improvements towards Dynamic 4D modelling what will be on benefit to specific the AEC industry sector to better understanding of a 4D model use.

I am kindly requesting your participation in the survey, which will involve a link to the questionnaire on the website: https://www.surveymonkey.co.uk/r/bogdanbutkovic and should only take 15-20 minutes of your time. Your answers will be kept confidential and you may choose at any time not to participate or withdraw from the survey with no any obligations.

Thank you for your willingness to assist this research survey. We value your participation.

Yours sincerely,

BOGDAN BUTKOVIC

Date Letter: 3rd January 2018

Dear Sir/Madam,

I refer here with to my email sent to your office on 11th December 2017 with a kind request to participate in the survey which involves a link to the online questionnaire on the website: https://www.surveymonkey.co.uk/r/bogdanbutkovic

I understand that Christmas breaks have affected slow responding of participants to this survey and in that regard kindly sending the reminder to that effect.

I am using this opportunity to wish you a very happy and prosperous New Year 2018.

Kind Regards,

BOGDAN BUTKOVIC

Date Letter: 18th January 2018

Dear Sir/Madam,

I hope you have a very good week. I refer here with to my email sent below to you on 3th January with a kind request to participate in the survey which involves a link to the online questionnaire website: https://www.surveymonkey.co.uk/r/bogdanbutkovic

I kindly send the reminder as the link will be closed on 28th February 2018 at midnight.

Kind Regards,

BOGDAN BUTKOVIC

Date Letter: 12th February 2018

Dear Sir/Madam,

I hope you are doing well. I refer here to my email earlier sent to you on 18th January with a kind request to participate in the survey which involves a link to the online questionnaire website: https://www.surveymonkey.co.uk/r/bogdanbutkovic

I am kindly reminding you once again to visit this web-site as the link will be closed on 28th February 2018 at midnight.

Kind Regards,

BOGDAN BUTKOVIC

Introduction of the questionnaire study

The main objective in this research is to identify the lack of awareness and potential needs for improvements towards Dynamic 4D modelling. The questionnaire seeks to obtain information from the specific AEC related disciplines (architects, contractors and project managers) on their current use and opinion of 4D modelling.

The survey contains general questions in addition to a range of qualitative and quantitative questions as scope of work with a dynamic 4D model use, identification of strengths, weaknesses and potential improvements. Observing, questioning and collecting data would also provide further development of the theoretical framework and would justify the needs for developing of novel software platform.

The survey was divided into four sections of information (personal, company, Dynamic 4D model and example tasks) in order to generate data concerning various companies which currently use BIM and their involvement in the construction industry. It is anticipated that these results will be compared with the results from the literature review findings.

It is anticipated that the survey can take from 15-20 minutes time to be completed.

*"**For information to participants in this survey:** all information received from the respondents will be kept strictly confidential and the participants shall reserve the right to refuse participation or withdraw from the research survey at any time."*

Questionnaire

1. Demographic Information

Q1 a) Occupation role

• Execution role: General	☐	Architect / Lead designer	☐
• Management role: CEO	☐	Contract Administrator	☐
• Client / Project sponsor	☐	Information Manager	☐
• Project Manager	☐	BIM Manager/BIM Co-ordinator	☐
• Building Surveyor	☐	Cost consultant/quantity surveyor	☐
• Construction Manager	☐	Structural Engineer	☐
• Main Contractor / Suppliers	☐	Site Engineer	☐
• Software Programmer	☐	Civil Engineer	☐
• Planner	☐	CDM Co-ordinator	☐

- Other (please give some details):________________________________

Q2 b) Number of years working in the industry

- 0-2 years ☐
- 2-4 years ☐
- 4-10 years ☐
- 10-15 years ☐
- More than 15 years ☐

---

2. Company Information

Q3 a) Main Project Sources

- Commercial ☐
- Residential ☐
- Highway ☐
- Rail ☐
- Other (please give some details):________________________________

Q4 b) Number of company employees

- 0-10 people ☐
- 10-20 people ☐
- 20-30 people ☐
- 30-40 people ☐
- More than 50 people ☐

Q5 c) Have you used BIM on any projects you have worked on?

- Yes ☐
- No ☐
- Other (please give some details):________________________________

Q6 d) On which the level have you been using BIM on the projects involved?

- Level 0 BIM ☐
- Level 1 BIM ☐
- Level 2 BIM ☐

Q7 e) Type of CAD / BIM software in use by the company. Please select all software used.

• *Autodesk* AutoCAD	☐	*Autodesk* Navisworks	☐
• *Autodesk* Revit	☐	*Autodesk* 3D Studio Max	☐
• *Trimble* SketchUp	☐	*Innovaya* Visual Simulation	☐
• *Trimble* Tekla	☐	*Bentley* MicroStation	☐
• *Graphisoft* ArchiCAD	☐	*Bentley* Project Wise Navigator	☐

- *Synchro Software Ltd* Synchro PRO ☐
- *VicoSoftware* Virtual Construction ☐
- Other (please give some details):________________________________

____

____

Q8 f) For how long company has implemented BIM into its practice?

- Have yet to implement ☐
- 0-1 year ☐
- 1-3 years ☐
- 3-5 years ☐

Q9 g) What planning software is used?

- Primavera ☐
- Asta Powerproject ☐
- Microsoft-Project ☐
- Other (please give some details):________________________________

3. Dynamic / 4D Modelling

Q10 a) Was 4D BIM used on any projects you have worked on?

- Yes ☐
- No ☐
- Other (please give some details):________________________________

Q11 b) If yes in what way was 4D BIM used in projects:

- Communicating the plan to client ☐
- As part of the project planning phase ☐
- Communicating between contractors / sub-contractors ☐
- Site logistics / space planning ☐
- Site safety briefings ☐
- Toolbox talks ☐
- Work package conflict detection ☐
- Other (please give some details):________________________________

____

Q12 c) Who was responsible for creating the 4D models of the project?

- Project manager ☐
- Project planner ☐
- CAD / BIM Technician ☐
- Other (please give some details):________________________________

Q13 d) Who do you believe should be responsible for creating a 4D model?

- Project manager ☐
- Project planner ☐
- CAD / BIM Technician ☐
- Other (please give some details):________________________________

Q14 e) If you have previously used 4D BIM on projects, how often did the simulation show changes to the project:
Every…

- 1 hour ☐
- 1 day ☐
- 2 days ☐
- 1 week ☐
- 2 weeks ☐
- 1 month ☐
- Other (please give some details):________________________________

Q15 f) Who has been responsible for specifying how often the simulation showed changes to the project?

- Answer:____

____

Q16 g) In your opinion, when using 4D models, should single elements in the 3D model be subdivided into smaller sub-elements of the models to show more detail during the 4D simulation?

- Yes ☐
- No ☐
- Sometimes ☐
- Don't know ☐

Q17 h) Do you agree that having a 4D model that shows more detail (i.e. more graphical detail and shorter time periods between model changes) can improve the identification of potential conflicts and clashes?

- Yes ☐
- No ☐
- Don't know ☐

Q18 i) Do you think you should have the ability to change the detail of the 4D model directly within the 4D software tool?

- Yes ☐
- No ☐
- Don't know ☐

---

4. Example Tasks

Q19-Q24 Please, tick the correct answer for the chosen time of construction activities.

When using a 4D model, please give an indication of how often you think the model should show changes for the following building example tasks: **(Example Tasks 1-28)**	Hourly	Daily	Two Days	Weekly	Fortnight	N/A
Q19 1) Site set up works	☐	☐	☐	☐	☐	☐
Q19 2) Foundation excavation	☐	☐	☐	☐	☐	☐
Q19 3) Piling operations	☐	☐	☐	☐	☐	☐
Q19 4) Foundation concrete pouring	☐	☐	☐	☐	☐	☐
Q19 5) Pile cap formation	☐	☐	☐	☐	☐	☐

When using a 4D model, please give an indication of how often you think the model should show changes for the following building example tasks: **(Example Tasks 1-28)**	Hourly	Daily	Two Days	Weekly	Fortnight	N/A
Q20 6) Foundation concrete curing	☐	☐	☐	☐	☐	☐
Q20 7) Erection of formwork	☐	☐	☐	☐	☐	☐
Q20 8) Slab creation / concrete	☐	☐	☐	☐	☐	☐
Q20 9) Erection of steelwork / framing	☐	☐	☐	☐	☐	☐
Q20 10) Erection of concrete frame	☐	☐	☐	☐	☐	☐
Q21 11) External walls construction (masonary work)	☐	☐	☐	☐	☐	☐
Q21 12) Internal walls creation (masonary work)	☐	☐	☐	☐	☐	☐
Q21 13) Internal walls (other)	☐	☐	☐	☐	☐	☐
Q21 14) Erection of scaffold / temporary works	☐	☐	☐	☐	☐	☐
Q21 15) Installation of cladding systems	☐	☐	☐	☐	☐	☐
Q22 16) First fix electrical	☐	☐	☐	☐	☐	☐
Q22 17) Ventilation work / ductwork installation	☐	☐	☐	☐	☐	☐
Q22 18) Water supply installation	☐	☐	☐	☐	☐	☐
Q22 19)Door installation	☐	☐	☐	☐	☐	☐
Q22 20) Window installation	☐	☐	☐	☐	☐	☐
Q23 21) Drainage activities	☐	☐	☐	☐	☐	☐
Q23 22) Insulation fixing / installation	☐	☐	☐	☐	☐	☐
Q23 23) Second fix electrical / ventilation / plumbing	☐	☐	☐	☐	☐	☐
Q23 24) External earthworks	☐	☐	☐	☐	☐	☐

When using a 4D model, please give an indication of how often you think the model should show changes for the following building example tasks: **(Example Tasks 1-28)**	Hourly	Daily	Two Days	Weekly	Fortnight	N/A
Q24 25) Landscaping	☐	☐	☐	☐	☐	☐
Q24 26) External drainage	☐	☐	☐	☐	☐	☐
Q24 27) Elevator installation	☐	☐	☐	☐	☐	☐
Q24 28) Roofing activities	☐	☐	☐	☐	☐	☐

(Reference: Cooke, B. (2011) *Construction Practice*. Chichester: Wiley)

Q25 Please, tick the correct answer for the chosen time of construction activities.

Please add any further example activities you feel may be relevant to a project. *(Example answer: 1: Trench excavation - Two Days)* *(Example answer: 2: HV Cables direct buried in the trench - Hourly)*	Hourly	Daily	Two Days	Weekly	Fortnight	N/A
1.	☐	☐	☐	☐	☐	☐
2.	☐	☐	☐	☐	☐	☐
3.	☐	☐	☐	☐	☐	☐
4.	☐	☐	☐	☐	☐	☐
5.	☐	☐	☐	☐	☐	☐

Q26 If you have any further comments on this questionnaire or the research please feel free to add these below.

____

____

____

Q27 Would you like to be contacted to see the findings of this research? If yes please enter your e-mail address below.

We appreciate your contribution in completing this survey research which is to demonstrate the needs for developing the novel software platform

Created by Bogdan Butkovic

Dropbox download link:

https://www.dropbox.com/s/ykasuociwzyrgq0/Questionnaire%202017.pdf?dl=0

Contract Review - pilot questionnaire comments

First responder – PhD Candidate in BIM at the University of Wolverhampton	Related to questions of the questionnaire	Response by Bogdan Butkovic
My first feedback is: do not say "Identify or confirm". Having these alternatives does not look very well. It is like you are doubting of what you are doing.	Introduction of the questionnaire study (first paragraph)	Comment accepted. Text should be written as: "Identify"
Research is to identify.	Introduction of the questionnaire study	Comment accepted as above
In the second paragraph you say, "the theoretical framework" but nobody knows anything about this framework. You have to introduce it first to the readers.	Introduction of the questionnaire study (second paragraph)	Comment noted. There is no sufficient space in introduction of survey study to include anything about framework neither readers should be introduced.
Why do you say potential? I don't get this adjective. I would simple say lack of awareness and needs for improvement towards dynamic 4D Modelling (would not use the article THE).	Introduction of the questionnaire study (first paragraph)	Comment accepted. Text should exclude the word "potential"
In this question, what is the difference you are looking for by putting the option "Yes" and the option "on some projects"?	Questions: 2c); 3a);	Comment accepted. The multiple choice "on some projects" was removed as the meaning with "Yes" is not significant.
If you are talking about BIM, I think that the questions needs to be reformulated.	Questions: 2c); 2d); 2f); 3a); 3b).	Comment noted.
I did not see these options, I would have thought about the BIM levels at all.	Questions: 2d);	Comment noted.
The question should go after the question "Have you used BIM?", so you could have a continuation. And I would eliminate the option "have not implemented BIM yet" since that is already answered in the question "Have you used BIM"?	Question 2f); 2c)	Comment noted. Questions are related in once instance to individual used of BIM while in another question to company use of BIM.
Purpose of the options "Yes" and "On some projects"?	Questions: 2c); 3a);	Comment accepted. The multiple choice "on some projects" was removed.
This question is quite difficult as the answer might not be specific. They can experience different frequency. I mean, that happen several times in project.	Question 3e); *If you have previously used 4D BIM on projects, how often did the simulation show changes to the project:*	Comment noted.
I just read the next question and think I don't understand what you meant with these frequencies		Comment noted.

Second responder – Senior Lecturer at the University of Wolverhampton	**Related to questions of the questionnaire**	**Response by Bogdan Butkovic**
I anticipate that you will need to add some ethical information, perhaps in the covering email. For example that the respondent will not be named in the research and how their information will be kept confidential.	As an addition to be included in Introduction part of survey	Comment accepted. Text to be included as follows: "For information to participants in this survey: all information received from respondents will be kept strictly confidential and the participants shall reserve the right to refuse participation or withdraw from research survey at any time."
An indication of the number of questions and the estimated time to complete the survey would be helpful. It took me 15 minutes but your respondents' timing may be different.	As an addition to be included in Introduction part of survey	Comment accepted. Text to be included as follows: "It is anticipated that the survey can take from 15-20 minutes time to be completed".
Consider putting the timings for the example tasks at regular intervals. Once you have answered the first few tasks, you can no longer see the timings as they have disappeared off the top of the screen.	Survey monkey	Comment noted.
In the first line of the explanation, there should be "is" after "research". The spread of the number of years' experience seems too small. I anticipate that most of the respondents will have been in the industry for over 10 years.	Introduction of the questionnaire study and question 1b).	Comment accepted. ("is" included) Comment possible accepted after discussion with the supervisor. Suggestion: 0-4; 4-10; 10-15; over 15
You conclude with a statement about justifying the need for a novel software platform. It seems to me that you need a convincing reason for including such a controversial statement. Perhaps your research aim is to demonstrate the need for such a novel software platform. However, this would seem to be a high risk strategy. For example, what if your research does demonstrate such a need?	Last conclusion statement: "We appreciate your contribution in completing this survey which hopefully will justify the needs for developing the novel software platform".	Comment accepted. Text amended as follows: "We appreciate your contribution in completing this survey research which is to demonstrate the needs for developing the novel software platform".
Finally and most importantly, rigorously review every question. Do they seek to answer your research aim, questions or objectives? If they do not, delete. Do you need to add any further questions? Also consider how you will analyse the data before you collect it.	All questions	Comment accepted and the questionnaire is currently under review through this pilot survey.

Third responder – Researcher at the University of Wolverhampton	**Related to questions of the questionnaire**	**Response by Bogdan Butkovic**
To identify or confirm – it shows you will conduct only on analysis i.e. either identify or confirm and even you do not know what are you going to do.	Introduction of the questionnaire study	The issue was already amended under first responder comment.
You have kept main contractor and suppliers in one option though they can be different.	Demography Information Question 1a)	Comment noted.
0-2 and 2-3 have clash. If someone has two years of experience then which he will choose? Moreover, there is no consistency in categories, for example, 0-2 years has a gap of 2 years and 2-3 years has a gap of only one year and so on. Same problem also persists in other questions as well down below.	Demography Information Question 1b)	Suggestion for a change was already proposed (from second responder) and to change the range of years of experience in industry.
Are highways and railways not a subset of transportation? If not, what's the difference between them?	Company Information Question 2a).	Comment accepted. An option "Transportation" was removed.
Search about relation between employee size and company's size. For example, which company is called SME and so on	Company Information Question 2b).	Comment noted.
Both (c) and (d) have same question but different options?	Company Information Questions 2c), 2d)	Comment accepted. 2 c): "Have you used BIM on any projects you have worked on?" 2 d): "On which level have you been using BIM on projects involved?"
Is Trimble SketchUp a BIM software?	Company Information Question 2e).	Comment noted.
Fourth responder – Senior Lecturer at the University of Salford	**No Response**	
Fifth responder – Dean at London South Bank University	**No Response**	
Dropbox download link: https://www.dropbox.com/s/2tf99aw8kryfwb9/Contract%20review.pdf?dl=0		

Responses – 1 Demographic Information (Q1 Q2)

	ID_Number	Q1	Q1_Other	Q2
1	1	Software Programmer		More than 15 years
2	2	Architect / Lead designer		4-10
3	8	Architect / Lead designer		4-10
4	9	BIM Manager / BIM Co-ordinator		10-15
5	11	Management role: CEO		2-4
6	12	BIM Manager / BIM Co-ordinator		10-15
7	13	Architect / Lead designer		More than 15 years
8	14	Management role: CEO		More than 15 years
9	15	BIM Manager / BIM Co-ordinator		10-15
10	16	Management role: CEO		More than 15 years
11	17	BIM Manager / BIM Co-ordinator		More than 15 years
12	18	BIM Manager / BIM Co-ordinator		4-10
13	20	BIM Manager / BIM Co-ordinator		10-15
14	21	BIM Manager / BIM Co-ordinator		10-15
15	23	BIM Manager / BIM Co-ordinator		4-10
16	24	BIM Manager / BIM Co-ordinator		More than 15 years
17	25	Architect / Lead designer		2-4
18	26	Project Manager		2-4
19	27	Management role: CEO		4-10
20	28	Other	BIM and Business consultant	More than 15 years
21	30	BIM Manager / BIM Co-ordinator		2-4
22	31	Planner		More than 15 years
23	32	Information Manager		4-10
24	34	Other	Director of Applied Technologies	2-4
25	35	BIM Manager / BIM Co-ordinator		4-10
26	36	BIM Manager / BIM Co-ordinator		10-15
27	37	BIM Manager / BIM Co-ordinator		More than 15 years
28	38	Other	BIM Consultant	More than 15 years
29	40	Civil Engineer		More than 15 years
30	41	Building Surveyor		More than 15 years
31	42	Architect / Lead designer		4-10
32	43	BIM Manager / BIM Co-ordinator		More than 15 years
33	44	Information Manager		More than 15 years
34	45	Architect / Lead designer		2-4

	ID_Number	Q1	Q1_Other	Q2
35	46	Cost consultant / quantity surveyor		2-4
36	47	Project Manager		4-10
37	48	Software Programmer		4-10
38	49	Information Manager		10-15
39	50	Other	4D Specialist	2-4
40	51	Information Manager		More than 15 years
41	52	Project Manager		10-15
42	53	Other	Director of Product Management (Software)	More than 15 years
43	55	Planner		10-15
44	57	Other	Digital Engineer	0-2
45	58	BIM Manager / BIM Co-ordinator		10-15
46	60	Planner		2-4
47	61	BIM Manager / BIM Co-ordinator		More than 15 years
48	63	BIM Manager / BIM Co-ordinator		4-10
49	65	BIM Manager / BIM Co-ordinator		More than 15 years
50	69	Project Manager		10-15
51	70	Execution role: General		More than 15 years
52	71	Main Contractor / Suppliers		10-15
53	72	Other	Senior VDC	4-10
54	73	BIM Manager / BIM Co-ordinator		4-10
55	74	Management role: CEO		4-10
56	75	Project Manager		More than 15 years
57	76	BIM Manager / BIM Co-ordinator		More than 15 years
58	77	Project Manager		10-15
59	78	BIM Manager / BIM Co-ordinator		10-15
60	80	BIM Manager / BIM Co-ordinator		10-15
61	83	Software Programmer		4-10

Responses – 2 Company Information (Q3 Q4 Q5 Q6)

	ID_Number	Q3	Q3_Other	Q4	Q5	Q5_Other	Q6_Level_0_BIM	Q6_Level_1_BIM	Q6_Level_2_BIM
1	1	Commercial		10-20	Yes		No	No	Yes
2	2	Residential		0-10	Yes		No	Yes	No
3	8	Other	Substations	More than 50	Yes		No	No	Yes
4	9	Commercial		More than 50	Yes		Yes	Yes	Yes
5	11	Commercial		0-10	No		Yes	No	No
6	12	All	Project dependant as we operate in many market sectors	More than 50	Yes		No	Yes	No
7	13	Commercial		More than 50	Yes		No	No	Yes
8	14	-		-	Yes		Yes	Yes	Yes
9	15	Highway		More than 50	Yes		No	No	Yes
10	16	All	All of the above and more	More than 50	Yes		Yes	Yes	Yes
11	17	Rail		More than 50	Yes		No	Yes	Yes
12	18	Rail		More than 50	Yes		No	Yes	Yes
13	20	Commercial		More than 50	Yes		No	No	Yes
14	21	Other	Education, custodial, defence	More than 50	Yes		No	Yes	Yes
15	23	Commercial		10-20	Yes		No	Yes	Yes
16	24	Commercial		More than 50	Yes		No	Yes	Yes
17	25	Commercial		10-20	Yes		No	Yes	No
18	26	Commercial		More than 50	Yes		No	Yes	No
19	27	All	Public sector	20-30	Yes		Yes	Yes	Yes
20	28	Commercial		0-10	Yes		No	No	Yes
21	30	Commercial		20-30	Yes		No	No	Yes
22	31	All	All Civil Infrastructure	More than 50	Yes		No	No	Yes
23	32	Commercial		More than 50	Yes		Yes	No	Yes
24	34	Commercial		30-40	Yes		Yes	Yes	Yes
25	35	Residential		More than 50	Yes		No	Yes	Yes
26	36	Commercial		0-10	Yes		No	Yes	Yes
27	37	Commercial		More than 50	Yes		No	Yes	Yes
28	38	Commercial		More than 50	Yes		No	No	Yes
29	40	Highway		More than 50	No		Yes	No	No
30	41	Other	Wet Infrastructure	More than 50	Yes		No	No	Yes

	ID_Number	Q3	Q3_Other	Q4	Q5	Q5_Other	Q6_Level_0_BIM	Q6_Level_1_BIM	Q6_Level_2_BIM
31	42	Commercial		More than 50	Yes		No	Yes	Yes
32	43	Commercial		More than 50	Yes		No	Yes	No
33	44	Highway		More than 50	Yes		No	No	Yes
34	45	Residential		30-40	Yes		No	Yes	No
35	46	Rail		30-40	No		Yes	No	No
36	47	Other	Healthcare	20-30	Yes		No	No	Yes
37	48	Commercial		20-30	Yes		No	No	No
38	49	All	All project sectors, including operations	More than 50	Yes		Yes	Yes	Yes
39	50	All	All above	30-40	Yes		No	No	Yes
40	51	All	All construction project types building, commercial, infrastructure etc	0-10	Yes		No	No	Yes
41	52	-		More than 50	Yes		No	No	Yes
42	53	Other	Infrastructure, Energy	30-40	Yes		No	Yes	Yes
43	55	Residential		More than 50	No		Yes	No	No
44	57	Other	Infrastructure	More than 50	Yes		No	No	Yes
45	58	All	All of the above	More than 50	Yes		Yes	Yes	Yes
46	60	Rail		10-20	No		No	No	No
47	61	Commercial		More than 50	Yes		No	Yes	Yes
48	63	Commercial		More than 50	Yes		No	No	Yes
49	65	Rail		0-10	Yes		Yes	Yes	Yes
50	69	Other	Program Management/Construction Management (PMCM)	More than 50	Yes		No	No	Yes
51	70	Commercial		More than 50	Yes		Yes	No	No
52	71	Rail		More than 50	Yes		Yes	Yes	Yes
53	72	Commercial		More than 50	Yes		No	No	Yes
54	73	Other	Government	More than 50	Yes		Yes	Yes	Yes
55	74	Other	Hospital	30-40	Yes		No	Yes	No
56	75	Commercial		More than 50	Yes		No	No	Yes
57	76	Commercial		More than 50	Yes		Yes	Yes	Yes
58	77	Commercial		More than 50	Yes		No	No	Yes
59	78	Other	Healthcare	More than 50	Yes		No	No	Yes
60	80	Commercial		More than 50	Yes		No	Yes	Yes
61	83	Commercial		30-40	Yes		Yes	Yes	No

Responses – 2 Company Information (Q7)

	ID_Number	Q7_AutoCAD	Q7_Revit	Q7_Navisworks	Q7_3DMax	Q7_SketchUp	Q7_Tekla	Q7_ArchiCAD	Q7_Synchro	Q7_Virtual_Co
1	1	No	Yes	Yes	No	No	No	No	Yes	No
2	2	Yes	No	No	No	Yes	No	No	No	No
3	8	Yes	Yes	Yes	No	No	Yes	No	No	No
4	9	Yes	Yes	Yes	No	Yes	No	No	Yes	No
5	11	Yes	No	No	No	No	No	No	No	No
6	12	No	No	Yes	No	No	No	No	Yes	No
7	13	Yes	Yes	Yes	Yes	No	No	No	No	No
8	14	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
9	15	Yes	Yes	Yes	Yes	No	No	No	No	No
10	16	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
11	17	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
12	18	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
13	20	No	Yes	Yes	No	No	No	No	Yes	No
14	21	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
15	23	Yes	Yes	Yes	Yes	No	No	No	No	No
16	24	Yes	Yes	Yes	No	Yes	No	Yes	No	No
17	25	Yes	Yes	No	No	No	No	No	No	No
18	26	Yes	No	No	No	No	No	No	No	No
19	27	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
20	28	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No
21	30	Yes	Yes	Yes	Yes	No	No	No	Yes	No
22	31	No	Yes	Yes	Yes	No	Yes	No	Yes	No
23	32	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
24	34	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No
25	35	No	Yes	Yes	No	No	No	No	No	No
26	36	No	Yes	Yes	No	No	No	No	No	No
27	37	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
28	38	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
29	40	Yes	No	No	No	No	No	No	No	No
30	41	Yes	Yes	No	No	No	No	No	No	No
31	42	Yes	Yes	Yes	No	No	No	No	No	No
32	43	Yes	Yes	Yes	No	No	No	No	No	No
33	44	Yes	Yes	Yes	No	No	No	No	Yes	Yes
34	45	Yes	Yes	Yes	Yes	Yes	No	No	No	No

	ID_Number	Q7_AutoCAD	Q7_Revit	Q7_Navisworks	Q7_3DMax	Q7_SketchUp	Q7_Tekla	Q7_ArchiCAD	Q7_Synchro	Q7_Virtual_Co
35	46	Yes	No	No	Yes	No	No	No	No	No
36	47	No	Yes	Yes	No	No	No	No	No	No
37	48	No	No	No	No	No	No	No	Yes	Yes
38	49	No	No	No	No	No	No	No	No	No
39	50	Yes	Yes	Yes	No	Yes	No	No	Yes	No
40	51	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
41	52	Yes	Yes	Yes	No	No	No	No	No	No
42	53	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No
43	55	Yes	No	No	No	No	No	No	No	No
44	57	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No
45	58	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
46	60	Yes	No	No	No	No	No	No	No	No
47	61	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
48	63	Yes	Yes	Yes	No	No	No	No	Yes	No
49	65	No	No	No	No	No	No	No	No	No
50	69	No	Yes	Yes	No	No	No	No	No	No
51	70	Yes	Yes	No	No	No	No	No	No	No
52	71	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
53	72	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No
54	73	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
55	74	Yes	Yes	Yes	No	No	Yes	No	No	No
56	75	Yes	Yes	No	No	No	Yes	Yes	No	No
57	76	Yes	Yes	Yes	Yes	No	Yes	No	No	No
58	77	Yes	Yes	Yes	No	No	Yes	No	Yes	No
59	78	No	Yes	Yes	No	No	No	Yes	Yes	No
60	80	No	Yes	Yes	No	No	No	No	Yes	No
61	83	No	Yes	Yes	No	Yes	Yes	No	No	No

Responses – 2 Company Information (Q7 Q8 Q9)

	ID_Number	Q7_Visual_Sim	Q7_MicroStation	Q7_Project_Wise	Q7_Other	Q7_Other_	Q8	Q9	Q9_Other
1	1	No	No	No	No		3-5	Other	Synchro
2	2	No	No	No	No		3-5	Other	Excel
3	8	No	No	No	No		0-1	Microsoft-Project	
4	9	No	Yes	No	No		0-1	Asta Powerproject	
5	11	No	No	No	Yes	Pythagoras	Have yet to implement	Other	Project Libre
6	12	No	No	No	Yes	Solibri, Rhino	1-3	Primavera	
7	13	No	Yes	Yes	No		1-3	Other	As Architects we don't use planning software
8	14	No	Yes	No	Yes	Unity, Dynamo	3-5	Asta Powerproject	
9	15	No	No	No	Yes	Autodesk Civil 3D	1-3	Microsoft-Project	
10	16	No	Yes	Yes	Yes	Asta power project, Solibri	3-5	All	All of the above
11	17	No	Yes	Yes	Yes	ProjectWise, Microsoft SharePoint, DesCartes, FME Workbench, ARC GIS	3-5	Primavera	
12	18	No	No	No	No		3-5	Primavera	
13	20	No	No	No	Yes	Solibri	3-5	Primavera	
14	21	No	No	No	Yes	Solibri Model Checker	1-3	Asta Powerproject	
15	23	No	No	No	No		1-3	Microsoft-Project	
16	24	No	No	No	Yes	BIMXtra, Viewpoint, Solibri Model Checker	3-5	Asta Powerproject	
17	25	No	No	No	No		1-3	Microsoft-Project	
18	26	No	No	No	No		3-5	Microsoft-Project	
19	27	No	Yes	Yes	Yes	Sitedesk and Deeo HUB	3-5	All	All of the above
20	28	No	Yes	Yes	No		3-5	Microsoft-Project	
21	30	No	No	No	Yes	Solibri	3-5	Microsoft-Project	

	ID_Number	Q7_Visual_Sim	Q7_MicroStation	Q7_Project_Wise	Q7_Other	Q7_Other_	Q8	Q9	Q9_Other
22	31	No	Yes	Yes	No		3-5	Primavera	
23	32	No	No	No	No		3-5	Microsoft-Project	
24	34	No	No	No	Yes	Unity, FULmax Keystone	3-5	All	Have used all of the above in the past
25	35	No	No	No	No		1-3	Asta Powerproject	
26	36	No	No	No	No		3-5	Microsoft-Project	
27	37	No	No	No	Yes	Solibri	3-5	Asta Powerproject	
28	38	No	No	No	No		3-5	Primavera	
29	40	No	No	No	No		Have yet to implement	Microsoft-Project	
30	41	Yes	Yes	No	No		3-5	Primavera	
31	42	No	No	No	No		3-5	Other	Don't know
32	43	No	No	No	No		Have yet to implement	Asta Powerproject	
33	44	No	No	Yes	Yes	4P viewpoint	1-3	Primavera	
34	45	No	No	No	No		1-3	Other	Newforma
35	46	No	No	No	No		Have yet to implement	Microsoft-Project	
36	47	No	No	No	No		3-5	Microsoft-Project	
37	48	Yes	Yes	Yes	Yes		3-5	Other	Synchro PRO
38	49	No	No	No	Yes	Solibri	3-5	Microsoft-Project	
39	50	No	No	No	No		3-5	Other	Synchro PRO
40	51	No	Yes	Yes	Yes	Numerous other solutions	3-5	All	All the above
41	52	No	No	No	No		1-3	Asta Powerproject	
42	53	No	Yes	No	Yes	Aveva PDMS, Intergraph Smart Plant 3D	3-5	Other	Synchro Pro, Synchro Scheduler
43	55	No	No	No	No		Have yet to implement	Asta Powerproject	
44	57	No	No	No	No		3-5	Primavera	
45	58	No	Yes	No	Yes	Autodesk Civil 3D, Cinema 4D, LSS, Solidworks	3-5	Asta Powerproject	
46	60	No	No	No	No		Have yet to implement	Primavera	

	ID_Number	Q7_Visual_Sim	Q7_MicroStation	Q7_Project_Wise	Q7_Other	Q7_Other_	Q8	Q9	Q9_Other
47	61	No	Yes	No	No		3-5	Other	Viewpoint For Projects Information Planner
48	63	No	No	No	No		3-5	Primavera	
49	65	No	Yes	Yes	Yes	AECOsim	1-3	Microsoft-Project	
50	69	No	No	No	No		3-5	Primavera	
51	70	No	No	No	No		3-5	Asta Powerproject	
52	71	No	Yes	Yes	No		3-5	Primavera	
53	72	No	No	No	No		3-5	Primavera	
54	73	Yes	Yes	Yes	Yes	Civil 3D vectorworks etc etc. we have over 400 pieces of software in use	3-5	Microsoft-Project	
55	74	No	No	No	No		3-5	Microsoft-Project	
56	75	No	Yes	No	No		1-3	Microsoft-Project	
57	76	No	Yes	Yes	Yes	Autodesk Civil 3D, Autodesk Inventor	3-5	Primavera	
58	77	No	No	No	Yes	BIM 360 Suite	3-5	Primavera	
59	78	No	No	No	No		3-5	Asta Powerproject	
60	80	No	No	No	No		3-5	Primavera	
61	83	No	No	No	No		0-1	Microsoft-Project	

Responses – 3 Dynamic / 4D Modelling (Q10 Q11)

	ID_Number	Q10	Q10_Other	Q11_Communicating_the_plan_to_client	Q11_As_part_of_the_project_planning_phase	Q11_Communicating_between_contractors_or_subcontractors	Q11_Site_logistics_or_space_planning
1	1	Yes		Yes	Yes	Yes	Yes
2	2	No		No	No	No	No
3	8	No		No	No	No	No
4	9	Yes		Yes	Yes	No	Yes
5	11	No		No	No	No	No
6	12	Yes		No	Yes	Yes	Yes
7	13	No		No	No	No	No
8	14	Yes		Yes	Yes	Yes	Yes
9	15	No		No	No	No	No
10	16	No		No	No	No	No
11	17	Yes		Yes	Yes	Yes	Yes
12	18	Yes		Yes	Yes	Yes	Yes
13	20	Yes		Yes	Yes	Yes	Yes
14	21	Yes		Yes	Yes	No	Yes
15	23	Yes		Yes	Yes	Yes	Yes
16	24	Yes		Yes	Yes	Yes	No
17	25	No		No	No	No	No
18	26	No		No	No	No	No
19	27	Yes		Yes	Yes	Yes	Yes
20	28	Yes		No	No	No	No
21	30	Yes		Yes	Yes	Yes	Yes
22	31	Yes		Yes	Yes	Yes	Yes
23	32	Yes		Yes	No	No	Yes
24	34	Yes		Yes	Yes	Yes	Yes
25	35	No		No	No	No	No
26	36	Yes		Yes	Yes	No	Yes
27	37	Yes		Yes	Yes	No	Yes
28	38	Yes		Yes	Yes	Yes	Yes
29	40	No		No	No	No	No
30	41	No		No	No	No	No
31	42	Other	Not sure what exactly is 4D BIM. BIM in time?	No	No	No	No

	ID_Number	Q10	Q10_Other	Q11_Communicating_the_plan_to_client	Q11_As_part_of_the_project_planning_phase	Q11_Communicating_between_contractors_or_subcontractors	Q11_Site_logistics_or_space_planning
32	43	No		No	No	No	No
33	44	No		No	No	No	No
34	45	No		No	No	No	No
35	46	No		No	No	No	No
36	47	Yes		No	No	No	Yes
37	48	Yes		Yes	Yes	Yes	Yes
38	49	Yes		Yes	Yes	Yes	Yes
39	50	Yes		Yes	Yes	Yes	Yes
40	51	Yes		Yes	Yes	Yes	Yes
41	52	Yes		No	Yes	Yes	No
42	53	Yes		Yes	Yes	Yes	Yes
43	55	No		No	No	No	No
44	57	Other	It is not used in extented level	Yes	No	No	No
45	58	Yes		Yes	Yes	Yes	Yes
46	60	No		No	No	No	No
47	61	Yes		Yes	No	Yes	No
48	63	No		No	No	No	No
49	65	Other	Yes but not on an ongoing basis more as proof of concept	No	No	No	No
50	69	Yes		Yes	Yes	No	No
51	70	No		No	No	No	No
52	71	Yes		Yes	Yes	Yes	No
53	72	Yes		Yes	Yes	Yes	Yes
54	73	Yes		Yes	Yes	No	No
55	74	Yes		Yes	Yes	Yes	Yes
56	75	No		No	No	No	No
57	76	Yes		Yes	Yes	No	Yes
58	77	Yes		Yes	Yes	Yes	Yes
59	78	Yes		Yes	Yes	Yes	Yes
60	80	Yes		Yes	Yes	No	No
61	83	Yes		No	Yes	No	No

Responses – 3 Dynamic / 4D Modelling (Q11)

	ID_Number	Q11_Site_safety_briefings	Q11_Toolbox_talks	Q11_Work_package_conflict_detection	Q11_Other	Q11_Other
1	1	Yes	Yes	Yes	No	
2	2	No	No	No	No	
3	8	No	No	No	No	
4	9	No	No	No	No	
5	11	No	No	No	No	
6	12	No	No	Yes	No	
7	13	No	No	No	No	
8	14	Yes	Yes	Yes	No	
9	15	No	No	No	No	
10	16	No	No	No	No	
11	17	Yes	Yes	Yes	Yes	Value Engineering, Temporary Works, Possession Planning (train movement, exclusions)
12	18	No	No	No	Yes	Verifying the P6 plan & for deconfliction
13	20	Yes	Yes	Yes	No	
14	21	No	No	No	No	
15	23	Yes	Yes	Yes	Yes	Direct relationship with programme & timings, cost data, estimating (quantitites), Value engineering through rationalising without compromising design in addition to establishing more efficient routing strategies for service distribution MEP, modularising to reduce time spent on site and reduce exposure to risk (H&S)
16	24	No	No	No	No	
17	25	No	No	No	No	
18	26	No	No	No	No	
19	27	Yes	Yes	Yes	No	
20	28	No	No	No	Yes	Assembly and disassembly planning for circular economy
21	30	No	No	Yes	No	
22	31	Yes	No	No	No	
23	32	No	No	No	No	
24	34	Yes	No	Yes	No	
25	35	No	No	No	No	
26	36	No	No	No	No	
27	37	No	No	No	No	

	ID_Number	Q11_Site_safety_briefings	Q11_Toolbox_talks	Q11_Work_package_conflict_detection	Q11_Other	Q11_Other
28	38	Yes	Yes	Yes	Yes	CDM reviews
29	40	No	No	No	No	
30	41	No	No	No	No	
31	42	No	No	No	No	
32	43	No	No	No	No	
33	44	No	No	No	No	
34	45	No	No	No	No	
35	46	No	No	No	No	
36	47	No	No	Yes	No	
37	48	Yes	No	Yes	No	
38	49	No	No	Yes	No	
39	50	Yes	No	No	No	
40	51	Yes	No	No	Yes	Many health and safety plans
41	52	No	No	Yes	No	
42	53	Yes	No	Yes	Yes	Site safety and risk planning, resource statusing & management
43	55	No	No	No	No	
44	57	No	No	No	No	
45	58	Yes	Yes	No	No	
46	60	No	No	No	No	
47	61	No	No	No	No	
48	63	No	No	No	No	
49	65	No	No	No	Yes	As proof of concept
50	69	No	No	No	No	
51	70	No	No	No	No	
52	71	No	No	No	No	
53	72	Yes	No	Yes	No	
54	73	No	No	No	No	
55	74	No	No	No	No	
56	75	No	No	No	No	
57	76	No	No	No	No	
58	77	Yes	No	No	No	
59	78	No	No	No	Yes	Construction sequence review
60	80	No	No	No	No	
61	83	No	No	No	No	

Responses – 3 Dynamic / 4D Modelling (Q12 Q13 Q14)

	ID_Number	Q12	Q12_Other	Q13	Q13_Other	Q14	Q14_Other
1	1	CAD / BIM Technician		Other	Integrated team	1 day	
2	2	N/A		CAD / BIM Technician		N/A	
3	8	N/A		Project planner		N/A	Never being used
4	9	Other	All of the above as a team	Other	All of the above as a team	N/A	4D Model not used during the construction phase
5	11	Project manager		Project manager		N/A	
6	12	Other	Planners/Schedulers internally and some external consultants	Project planner		1 week	
7	13	N/A		Project planner		1 month	
8	14	CAD / BIM Technician		CAD / BIM Technician		1 day	
9	15	N/A		Project planner		N/A	
10	16	Other	Planner and BM (BIM Manager)	Project planner		Other	Vairies project to project
11	17	Other	Supply Chain BIM Team D&B, Internal Project BIM Team in early development	Other	An Integrated D&B Team at any stage of a project where logistical challenges are evident	1 month	Varies - rarely monthly - more used on daily and hourly timelines noting limited time for rail projects
12	18	CAD / BIM Technician		Project planner		1 hour	Programme and 4D model updated every 6 hours
13	20	CAD / BIM Technician		CAD / BIM Technician		1 month	
14	21	Project planner		Project planner		1 hour	
15	23	Other	Stage 4a by Design Consultant > Inherited by our client, 1st Tier contractor, then our company are commissioned to evolve the model to LOD600 & establish	Other	There a great number of people who have a role in the creation of the model, varying for Arch, MEP & Structural, in addition to this I believe that	1 week	

			Level 2 processes through design changes & subsequent updates to programme and model		there shouldn't be one person responsible for creating the 4D model. The Client has responsibility, Architect's & Technologists, Structural Engineers & Technicians, Senior Mechanical & Electrical Engineers, BIM coordinators & Technicians, QS, document controllers overseen by Project Managers, Design Managers & BIM Managers - to have a team communication the model requirement in line with a project specific and well put together execution plan. Subjects should each have access to the CDE and be able to communicate with all parties involved by Design Team Meetings, Progress Meeting & toolbox talk		
16	24	Project planner		Project planner		1 week	
17	25	N/A		CAD / BIM Technician		N/A	
18	26	N/A		CAD / BIM Technician		N/A	
19	27	Other	Design manager in consultant created the models working with others listed above - collaborative effort	Project planner	Collaborative effort between the design, planning and delivery team.	1 hour	
20	28	Project planner		Project planner		1 day	
21	30	CAD / BIM Technician		CAD / BIM Technician		1 day	
22	31	Project planner	Planner delivers 4D plan and Modeler delivers 3D model	Project planner	Planner delivers 4D plan, Modeler delivers 3D model	1 week	
23	32	Other	Internal BIM Co-ordinator (4D Specialist)	Project manager		1 month	

	ID_Number	Q12	Q12_Other	Q13	Q13_Other	Q14	Q14_Other
24	34	Project planner		Project planner		Other	Depended on the project, but more importnatly, the projects 4D resolution - we have planned down to 15 minutie intervals before, but typicall plan to 1 day resolution unless we need more detail
25	35	N/A		N/A		1 week	
26	36	CAD / BIM Technician		Project planner		1 month	
27	37	CAD / BIM Technician		Project planner		1 week	
28	38	CAD / BIM Technician		CAD / BIM Technician		1 hour	1 day, 1 week, 1 month
29	40	CAD / BIM Technician		Project manager		2 days	
30	41	Project planner		Project planner		N/A	
31	42	N/A		N/A		N/A	
32	43	CAD / BIM Technician		CAD / BIM Technician		1 week	
33	44	N/A		Project planner		N/A	
34	45	N/A		Project planner		N/A	
35	46	CAD / BIM Technician		Project planner		N/A	
36	47	Other	Construction BIM Specialist	Other	Construction BIM Specialist	1 week	
37	48	Project planner		Project planner		Other	5 minutes
38	49	CAD / BIM Technician		Project planner		1 week	1 week, 1 month
39	50	Other	4D specialist	Other	Start from Planner but everybody on the jobsite should use it	2 days	

	ID_Number	Q12	Q12_Other	Q13	Q13_Other	Q14	Q14_Other
40	51	Project planner		Project planner		1 week	
41	52	CAD / BIM Technician		Other	Architect	1 week	
42	53	Other	VDC Specialist	Other	Designated person with both: planning and modelling skills - e.g. VDC Specialist, Digital Engineer, etc.	Other	Any time interval
43	55	N/A		CAD / BIM Technician		N/A	
44	57	Other	Digital Engineering Team	Other	BIM Specialist	1 week	
45	58	CAD / BIM Technician		Project planner		1 week	
46	60	N/A		CAD / BIM Technician		N/A	
47	61	Other	Architect	N/A		N/A	
48	63	N/A		N/A		N/A	
49	65	CAD / BIM Technician		Other	I think a BIM planner / manager some who can both create the models and attached links to the models.	1 week	
50	69	CAD / BIM Technician		Project planner		1 month	
51	70	CAD / BIM Technician		CAD / BIM Technician		N/A	
52	71	Project planner		Project planner		1 month	
53	72	Other	VDC engineer belong to the project controls department so he is connecting the planning team with the BIM team.	Other	VDC engineer	1 week	
54	73	Other	Lead Designer	Other	Whoever has won that particular part of the contract	Other	Construction milestone
55	74	CAD / BIM Technician		Project manager		1 week	
56	75	N/A		N/A		N/A	
57	76	CAD / BIM Technician		Project planner		1 week	
58	77	CAD / BIM Technician		Project planner		1 week	

	ID_Number	Q12	Q12_Other	Q13	Q13_Other	Q14	Q14_Other
59	78	Project planner		Project planner		1 month	
60	80	Other	Third party 4D specialist consultant	Project planner		1 day	
61	83	Project planner		Other	Last Planners - Embrace crew leaders, foremen, superintendent planning input.	1 month	

Responses – 3 Dynamic / 4D Modelling (Q15 Q16 Q17 Q18)

	ID_Number	Q15	Q15_Answer	Q16	Q17	Q18
1	1	None		Yes	Yes	Yes
2	2	None		Yes	Yes	Yes
3	8	None		Yes	Yes	No
4	9	Answer	Information Manager	Sometimes	No	No
5	11	None		Yes	Yes	Yes
6	12	Answer	Collective review with the Senior Management Team, with input of the lead project planner, project manager and design manager.	Yes	Yes	No
7	13	Project Manager	Project Lead	Sometimes	Yes	Yes
8	14	Planner	Planner, Project Manager, Project Director	Sometimes	Yes	Yes
9	15	None		No	Yes	No
10	16	None	Project needs - experience	Sometimes	Yes	No
11	17	Answer	Depends on the task and what we are trying to achieve - possession work can be very intense, hourly is very common for management and proof of method in advance of works. Can be used for live re-planning (not too often). Occasionally used for long-range logistical planning (i.e. large programme over operational assets - or overlapping programmes of work.	Sometimes	Yes	Yes
12	18	Project Manager	Project Delivery	Sometimes	Yes	Yes
13	20	Project Manager	BIM Project and Project Manger	Sometimes	Don't know	Yes
14	21	Planner	Planner	Sometimes	Yes	Don't know
15	23	Answer	Our company, as those responsible for M&E coordination, it is critical that all of the information we have is current, therefore when federating newly received models and using Solibri Model Comparison & Navis Manage to check for changes we are often the first to know that a change has taken place, in other instances a design change report will have been raised to which we will act on. On a number of project a lot of changes can be missed if not communicated effectively.	Sometimes	Yes	Yes
16	24	Answer	A combination of the BIM Manager and Planner	Sometimes	Yes	Yes
17	25	None		Yes	Yes	Yes
18	26	None		Don't know	Yes	Yes
19	27	Planner	Driven by the client, involved planning and project management team. Change time is related to risk. Higher risk = more info more often	Sometimes	Yes	Don't know
20	28	Planner	Derived from the time units in the planning schedules	Sometimes	Yes	Yes
21	30	Project Manager	Client and Project Manager	Yes	Yes	No

	ID_Number	Q15	Q15_Answer	Q16	Q17	Q18
22	31	Project Manager	Project Manager	Yes	No	No
23	32	Answer	Contractor	Sometimes	Yes	No
24	34	None	This question does not make sense - the project simulation and schedule will show clashes depending on rules set - We would normally plan a day at a time, and anything that pushes the plan over a set tolerance would be flagged, showing delay to critical path	Sometimes	Yes	Don't know
25	35	BIM Manager / BIM Co-ordinator	BIM Coordinator	Sometimes	Yes	No
26	36	Planner	Project Manager and Planner	Don't know	No	No
27	37	Planner	Combination of planning team and project leadership team	Sometimes	Yes	No
28	38	Planner	Planner	Yes	Yes	Yes
29	40	Answer	MD (Managing Director)	Yes	Yes	Yes
30	41	None		Yes	Yes	Yes
31	42	None		Don't know	Don't know	Don't know
32	43	Planner	Client, Project Planner and Design Manager	Sometimes	Yes	Yes
33	44	None		Sometimes	Yes	Yes
34	45	None		Sometimes	Yes	Yes
35	46	Planner	Project Planner	Sometimes	Yes	Yes
36	47	Project Manager	Project Manager	Yes	Yes	Yes
37	48	Answer	Consultant	Yes	Yes	Yes
38	49	BIM Manager / BIM Co-ordinator	BIM Management	Yes	Yes	Yes
39	50	Planner	Scheduler	Yes	Yes	Yes
40	51	Planner	The planner and the number of impact delays.	Sometimes	No	No
41	52	Planner	Planner and BIM Specialist	Sometimes	Yes	Yes
42	53	Answer	Daily planning (Planner), Weekly updates (Planner, Project Manager, Construction Manager) and Monthly updates (Contract, Client)	Sometimes	Yes	No
43	55	None		Yes	Yes	Yes
44	57	Answer	Digital Engineering Team	Yes	Yes	Yes
45	58	None		Yes	Yes	Yes
46	60	None		Yes	Yes	Don't know
47	61	None		Sometimes	Yes	Yes
48	63	None		Yes	Yes	Yes
49	65	None		Sometimes	Yes	Yes
50	69	None		Sometimes	Don't know	No
51	70	None		Yes	Yes	Yes

	ID_Number	Q15	Q15_Answer	Q16	Q17	Q18
52	71	Planner	Planner and project manager	Sometimes	Don't know	Yes
53	72	Answer	Construction team	Sometimes	Yes	Yes
54	73	Answer	The Client in collaboration with the Lead Designer	Sometimes	Yes	Yes
55	74	Project Manager		No	Yes	Yes
56	75	None		Don't know	Don't know	Don't know
57	76	Answer	The consultant as it was just indicative from the design point of view and not from a buildability point of view	Sometimes	Yes	No
58	77	Project Manager		Sometimes	Yes	No
59	78	Project Manager	Company protocol, project / package manager	No	No	No
60	80	Planner	Planner since it's linked to their programme which is broken up into days	Sometimes	Yes	Yes
61	83	Answer	Whenever it can done, it usually gets less and less often as the project progresses.	Yes	Yes	Don't know

Responses – 4 Example Tasks (Q19 Q20)

	ID_Number	Q19_1	Q19_2	Q19_3	Q19_4	Q19_5	Q20_6	Q20_7	Q20_8	Q20_9	Q20_10
1	1	Daily	Daily	Hourly	Daily	Daily	Daily	Daily	Daily	Daily	Daily
2	2	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
3	8	Hourly	Daily	Daily	Daily	Daily	Fortnight	Daily	Weekly	Daily	Daily
4	9	N/A	Fortnight	Fortnight	Fortnight	Fortnight	N/A	N/A	N/A	Fortnight	Fortnight
5	11	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
6	12	Fortnight	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
7	13	Weekly	Two days	Two days	Two days	Two days	Weekly	Weekly	Weekly	Weekly	Weekly
8	14	Weekly	Weekly	Weekly	Two days	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
9	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	16	Weekly	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
11	17	Daily	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly
12	18	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
13	20	Daily	Daily	Daily	Hourly	Daily	Daily	Daily	Hourly	Daily	Daily
14	21	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
15	23	Daily	Daily	Hourly	Daily	Hourly	Daily	Hourly	Daily	Hourly	Hourly
16	24	Daily	Daily	Daily	Daily	Daily	Hourly	Daily	Daily	Daily	Daily
17	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18	26	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
19	27	Daily	Daily	Daily	Hourly	Daily	Two days	Daily	Two days	Daily	Daily
20	28	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
21	30	Daily	Daily	Daily	Daily	Daily	Two days	Daily	Daily	Daily	Daily
22	31	Weekly	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Weekly	Weekly
23	32	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
24	34	Daily	Daily	Hourly	Daily	Daily	Daily	Hourly	Daily	Hourly	Hourly
25	35	Weekly	Two days	Two days	Two days	Two days	Weekly	Two days	Two days	Two days	Two days
26	36	N/A	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight
27	37	Fortnight	Weekly	Fortnight	Weekly	Fortnight	Fortnight	Weekly	Two days	Daily	Weekly
28	38	Daily	Daily	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Daily	Daily
29	40	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
30	41	Weekly	Daily	Daily	Daily	Weekly	Weekly	Hourly	Daily	Daily	Daily
31	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
32	43	Weekly	Two days	Two days	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
33	44	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
34	45	Two days	Weekly	Two days	Two days	Weekly	Weekly	Two days	Weekly	Weekly	Weekly

	ID_Number	Q19_1	Q19_2	Q19_3	Q19_4	Q19_5	Q20_6	Q20_7	Q20_8	Q20_9	Q20_10
35	46	Daily	Two days	Two days	Daily	Daily	Daily	Daily	Daily	Daily	Daily
36	47	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
37	48	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly
38	49	Weekly	Weekly	Daily	Weekly	Weekly	Weekly	Weekly	Weekly	Daily	Daily
39	50	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
40	51	Daily	Daily	Daily	Daily	Daily	N/A	Daily	Daily	Daily	Daily
41	52	Daily	Daily	Daily	Daily	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
42	53	Weekly	Daily	Daily	Daily	Daily	Weekly	Daily	Daily	Daily	Daily
43	55	Daily	Daily	Daily	Daily	Two days	Hourly	Hourly	Daily	Daily	Weekly
44	57	Daily	Weekly	Weekly	Two days	N/A	Two days	Daily	Daily	Daily	Daily
45	58	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
46	60	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
47	61	Weekly	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
48	63	Weekly	Fortnight	Fortnight	Fortnight	Fortnight	N/A	Fortnight	Weekly	Weekly	Weekly
49	65	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
50	69	Weekly	Daily	Daily	Daily	Daily	Daily	Daily	Two days	Two days	Two days
51	70	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
52	71	Two days	Two days	Weekly	Two days	Two days	Weekly	Two days	Weekly	Weekly	Weekly
53	72	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days
54	73	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
55	74	Two days	Weekly	Weekly	Weekly	Weekly	Weekly	Two days	Two days	Daily	Two days
56	75	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
57	76	Daily	Daily	Daily	Daily	Daily	Weekly	Two days	Two days	Daily	Two days
58	77	Two days	Two days	Daily	Daily	Daily	Two days	Daily	Daily	Daily	Daily
59	78	Weekly	Weekly	Weekly	Weekly	Weekly	Daily	Weekly	Daily	Daily	Weekly
60	80	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
61	83	Daily	Daily	Hourly	Hourly	Hourly	Daily	Hourly	Daily	Hourly	Hourly

Responses – 4 Example Tasks (Q21 Q22)

	ID_Number	Q21_11	Q21_12	Q21_13	Q21_14	Q21_15	Q22_16	Q22_17	Q22_18	Q22_19	Q22_20
1	1	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
2	2	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
3	8	Daily	Daily	Daily	Daily	Daily	Hourly	Hourly	Hourly	Hourly	Hourly
4	9	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	N/A	Fortnight
5	11	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
6	12	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
7	13	Weekly	Weekly	Weekly	Weekly	Weekly	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight
8	14	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
9	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	16	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
11	17	Daily	Daily	Daily	Daily	Daily	N/A	N/A	N/A	N/A	N/A
12	18	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
13	20	Daily	Daily	Daily	Hourly	Daily	Daily	Daily	Daily	Daily	Daily
14	21	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
15	23	Daily	Daily	Daily	Weekly	Weekly	Hourly	Hourly	Hourly	Hourly	Hourly
16	24	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
17	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18	26	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
19	27	Two days	Two days	Two days	Daily	Two days	Weekly	Weekly	Weekly	Weekly	Weekly
20	28	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
21	30	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
22	31	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Weekly	Daily	Daily
23	32	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
24	34	Daily	Daily	Daily	Hourly	Hourly	Daily	Daily	Daily	Daily	Daily
25	35	Daily	Daily	Daily	Hourly	Hourly	Weekly	Two days	Two days	Weekly	Weekly
26	36	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight
27	37	Weekly	Weekly	Two days	Two days	Two days	Two days	Two days	Two days	Daily	Daily
28	38	Weekly	Weekly	Weekly	Daily	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
29	40	Daily	Daily	Daily	Daily	Daily	Daily	Two days	Two days	Two days	Two days
30	41	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
31	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
32	43	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
33	44	N/A	N/A	N/A	Weekly	N/A	Weekly	Weekly	Two days	Two days	Two days
34	45	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Fortnight	Two days	Fortnight

	ID_Number	Q21_11	Q21_12	Q21_13	Q21_14	Q21_15	Q22_16	Q22_17	Q22_18	Q22_19	Q22_20
35	46	Two days	Two days	Daily	Daily	Daily	Two days	Two days	Two days	Daily	Daily
36	47	Daily	Daily	Daily	Daily	Hourly	Hourly	Hourly	Hourly	Daily	Daily
37	48	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly
38	49	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
39	50	Weekly	Weekly	Weekly	Weekly	Weekly	Daily	Daily	Daily	Daily	Daily
40	51	Two days	Two days	Two days	Two days	Two days	Daily	Daily	Daily	Daily	Daily
41	52	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
42	53	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
43	55	Weekly	Weekly	Weekly	Two days	Weekly	Weekly	Weekly	Weekly	Daily	Daily
44	57	Daily	Daily	Daily	Daily	Daily	Two days	Two days	Two days	Two days	Two days
45	58	Daily	Daily	Daily	Daily	Daily	Weekly	Weekly	Weekly	Daily	Daily
46	60	Weekly	Weekly	Weekly	Weekly	Weekly	Fortnight	Weekly	Fortnight	Fortnight	Fortnight
47	61	Daily	Daily	Daily	Two days	Daily	Daily	Daily	Daily	Daily	Daily
48	63	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
49	65	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
50	69	Two days	Two days	Two days	Two days	Two days	Weekly	Two days	Weekly	Weekly	Weekly
51	70	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
52	71	Weekly	Weekly	Weekly	Weekly	Two days	Weekly	Weekly	Weekly	Weekly	Weekly
53	72	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days
54	73	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
55	74	Daily	Daily	Daily	Daily	Daily	Daily	Hourly	Hourly	Two days	Two days
56	75	Daily	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days
57	76	Two days	Two days	Two days	Daily	Daily	Daily	Daily	Daily	Daily	Daily
58	77	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days
59	78	Weekly	Weekly	Weekly	Two days	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
60	80	Daily	Daily	Daily	Daily	Daily	N/A	Daily	Daily	Daily	Daily
61	83	Daily	Daily	Hourly	Daily	Daily	Hourly	Hourly	Hourly	Hourly	Hourly

Responses – 4 Example Tasks (Q23 Q24)

	ID_Number	Q23_21	Q23_22	Q23_23	Q23_24	Q24_25	Q24_26	Q24_27	Q24_28
1	1	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
2	2	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
3	8	Hourly	Hourly	Hourly	Daily	Daily	Daily	Hourly	Hourly
4	9	N/A	N/A	N/A	Fortnight	Fortnight	N/A	N/A	Fortnight
5	11	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
6	12	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
7	13	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight
8	14	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
9	15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10	16	Daily	Daily	Daily	Weekly	Weekly	Weekly	Weekly	Daily
11	17	Hourly	N/A	N/A	Hourly	Hourly	Hourly	N/A	Hourly
12	18	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
13	20	N/A	N/A	Daily	Daily	Two days	Two days	Daily	Daily
14	21	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
15	23	Hourly	Hourly	Hourly	Daily	Daily	Daily	Daily	Daily
16	24	Daily	Daily	Daily	Daily	Weekly	Daily	Daily	Daily
17	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18	26	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
19	27	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Two days	Two days
20	28	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
21	30	Daily	Daily	Daily	Daily	Two days	Daily	Daily	Daily
22	31	Daily	Daily	Daily	Two days	Two days	Daily	Two days	Two days
23	32	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
24	34	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
25	35	Two days	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Two days
26	36	Fortnight	N/A	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight
27	37	Two days	Daily	Two days	Daily	Two days	Two days	Weekly	Daily
28	38	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
29	40	Daily	Two days	Daily	Two days	Weekly	Weekly	Weekly	Weekly
30	41	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
31	42	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
32	43	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
33	44	Weekly	N/A	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
34	45	Fortnight	Fortnight	Fortnight	Two days	Two days	Fortnight	Daily	Two days

	ID_Number	Q23_21	Q23_22	Q23_23	Q23_24	Q24_25	Q24_26	Q24_27	Q24_28
35	46	Daily	Daily	Weekly	Weekly	Weekly	Weekly	Two days	Two days
36	47	Hourly	Hourly	Hourly	Two days	Two days	Daily	Hourly	Daily
37	48	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly	Hourly
38	49	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
39	50	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
40	51	Daily	Daily	Daily	Daily	Two days	Two days	Two days	Two days
41	52	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Daily	Weekly
42	53	Daily	Daily	Daily	Daily	Weekly	Daily	Daily	Daily
43	55	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Two days	Weekly
44	57	Two days	Two days	Weekly	Weekly	Two days	Two days	Two days	Two days
45	58	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Daily
46	60	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight	Fortnight
47	61	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
48	63	Weekly	Weekly	Weekly	Weekly	Fortnight	Fortnight	Weekly	Weekly
49	65	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
50	69	Weekly	Weekly	Weekly	Weekly	Fortnight	Fortnight	Fortnight	Weekly
51	70	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
52	71	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
53	72	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days
54	73	Daily	Daily	Daily	Daily	Daily	Daily	Daily	Daily
55	74	Daily	Two days	Daily	Two days	Weekly	Weekly	Daily	Daily
56	75	Two days	Two days	Two days	Two days	Two days	Two days	Two days	Two days
57	76	Daily	Daily	Daily	Daily	Daily	Daily	Two days	Two days
58	77	Two days	Two days	Two days	Two days	Weekly	Two days	Weekly	Weekly
59	78	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly	Weekly
60	80	Daily	N/A	N/A	Daily	Daily	Daily	Daily	Daily
61	83	Hourly	Hourly	Hourly	Daily	Daily	Daily	Daily	Hourly

Responses – 4 Example Tasks (Q25 Q26 Q27)

	ID_Number	Q25_Example_Activities	Q26_Comments	Q27
1	1	No	No	ETHICS
2	2	No	No	ETHICS
3	8	No	No	No
4	9	No	No	No
5	11	No	No	ETHICS
6	12	No	No	No
7	13	No	There are so many aspects of 4D which have a bearing on how it is used and the benefits it can offer. Much depends on the nature of the scheme (from Nuclear to Airports) and much depends on the level of risks/complexity. A small school extension would I suggest require less demanding 4D work that a new nuclear facility being constructed adjacent to other existing nuclear works.	ETHICS
8	14	No	No	ETHICS
9	15	No	No	No
10	16	No	No	No
11	17	Demolition - hourly – daily recovery of material - hourly - daily	The question on how often is somewhat difficult to say - it really depends on the stage of works and the purpose of the 4D – the example I have focussed on is site possession work. My honest feeling is you need to use where appropriate to help solutions, manage risk, at whatever frequency and level of graphical information and programme granularity is needed. Also there is an issue in model assembly and programme package assembly Finally there is a challenge around integration of information and software - to avoid re-work and duplicate models and sources of data.	ETHICS
12	18	No	No	No
13	20	No	No	ETHICS
14	21	No	The complexity of a project and programme length will determine how a 4D model should be broken down, as will the intended use of a 4D model. More complex tasks may require a more detailed breakdown.	ETHICS
15	23	No	No	ETHICS
16	24	No	No	No
17	25	No	No	No

	ID_Number	Q25_Example_Activities	Q26_Comments	Q27
18	26	No	No	No
19	27	This is driven by the complexity of the project. The higher the identified risk to the programme, the closer together the updates should be. There also needs to be scope for contingencies and issues e.g. weather and concrete pours. I think it's very challenging to have a one site fits all answer to your questions.	As stated earlier, the projects risk should dictate the frequency of the programme steps otherwise the benefit of 4D will be completely lost. The hardest thing in planning is handling unexpected and change, 4D when applied correctly should help identify the risk and the options rather than a prescriptive timeline.	ETHICS
20	28	No	No	ETHICS
21	30	No	No	No
22	31	No	The questionnaire centres on building, the Civil construction industry have a very different outlook on how 4D Planning is engineered.	ETHICS
23	32	No	The ultimate aspiration has to be live tracking of components from manufacture to site to install, having a live linked model to give real time progress will be invaluable. However at present the linking of model to 4D is a time intensive task so weekly updates are feasible.	No
24	34	No	No	No
25	35	No	No	No
26	36	No	No	ETHICS
27	37	Commissioning and testing daily Logistics deliveries and consolidation points daily	No	No
28	38	Trades locations - daily	Poor questionnaire - no indication of multiple choice or single selection. Research seems basic and limited	No
29	40	No	No	No
30	41	No	No	No
31	42	No	Sorry I didn't get into group who deals with 4D BIM. In our office we deal with construction stages and deliveries agreed in BIM Execution Plan. It is quite complex document and 4D BIM might be already part of it. I would love to answer to your 4D BIM questionnaire, but I need more time to soak in. And I thought I'm good at BIM... Much to learn...	ETHICS
32	43	No	No	No
33	44	Retaining walls	No	ETHICS
34	45	No	No	ETHICS
35	46	No	No	No
36	47	No	No	No

	ID_Number	Q25_Example_Activities	Q26_Comments	Q27
37	48	No	need to be able to schedule, simulate and monitor progress with digital round trip data integration	ETHICS
38	49	No	As important is recording the actual not just the planned - Update will be the limitation on collection of data	No
39	50	No	How detailed the 4D needs to be should depend on at what stage the project/ construction is at.	ETHICS
40	51	No	On housing projects great value was achieved by modelling every aspect of the construction activity. particularly the groundwork's and regrading.	ETHICS
41	52	Temporary site welfare install/removal (daily) Main welfare install/removal (daily) Temporary power and water connections (Daily)	Early involvement of all stakeholders is essential to get the most out of BIM. Including relevant training and software install onto computers.	No
42	53	All work - due to the nature of 4D simulation every work can/should be refreshed daily	Thank you for taking 4D BIM as a topic for your research. This is very important to the industry.	ETHICS
43	55	No	No	No
44	57	No	No	ETHICS
45	58	No	No	No
46	60	No	No	No
47	61	No	No	No
48	63	No	No	ETHICS
49	65	Cable Trough - Hourly	Finding the appropriate software to produce to a 4D in as quick and efficient time with great visuals has proved to be challenging. This is the level we have been trying to replicate, with a minimum of software change overs: https://www.visual5d.com/	ETHICS
50	69	No	No	No
51	70	No	No	ETHICS
52	71	No	No	No
53	72	Crane installation major equipment	No	ETHICS
54	73	No	No	No
55	74	No	No	ETHICS
56	75	No	No	No
57	76	No	No	ETHICS
58	77	No	No	ETHICS
59	78	No	No	No
60	80	Temp works - welfare, hoarding, hoists, cranes – all daily	No	No

	ID_Number	Q25_Example_Activities	Q26_Comments	Q27
61	83	Inspections - Hourly	Definitely want to see your results if you can share them! I can tell we think alike by the questions.	ETHICS

Grouped Occupation Roles

Q1a: Occupation Role

Occupation role		Q1a: (Occupation role)			
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Execution role: General	1	1.6	1.6	1.6
	Management role: CEO	5	8.2	8.2	9.8
	Project Manager	6	9.8	9.8	19.7
	Building Surveyor	1	1.6	1.6	21.3
	Main Contractor / Suppliers	1	1.6	1.6	23.0
	Software Programmer	3	4.9	4.9	27.9
	Planner	3	4.9	4.9	32.8
	Architect / Lead designer	6	9.8	9.8	42.6
	Information Manager	4	6.6	6.6	49.2
	BIM Manager / BIM Co-ordinator	22	36.1	36.1	85.2
	Cost consultant / quantity surveyor	1	1.6	1.6	86.9
	Civil Engineer	1	1.6	1.6	88.5
	Other	7	11.5	11.5	100.0
	Total	**61**	**100.0**	**100.0**	

Q1a: Grouped Occupation Role (Updated)

Grouped Occupation role		Q1a: (Grouped Occupation role)			
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	BIM Manager / Coordinator / Information Manager	26	42.6	42.6	88.5
	Lead Designer / Engineer	9	14.8	14.8	45.9
	Project Manager / Planner	17	27.9	27.9	27.9
	Surveyor	2	3.3	3.3	31.1
	Others	7	11.5	11.5	100.0
	Total	**61**	**100.0**	**100.0**	

Appendix F: Details of the Companies Surveyed

	Companies (NO NAMES FOR ETHICS)	Location	Emails sent	Date	Response	Reminder	Response	Reminder	Response	Reminder	Response
1	Civil Engineering	Hampshire, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
2	3D and 4D Construction Simulation	Warwickshire, UK	Yes	11.12.17		03.01.18	2	-		-	
3	Construction	Greater Manchester, UK	Yes	11.12.17		03.01.18	2	-		-	
4	Management Consulting	Greater London, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
5	Construction	Gloucestershire, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
6	Architecture and Planning	Greater London, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
7	Construction	Surrey, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
8	Construction (BIM)	Greater Manchester, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
9	Construction	Yorkshire, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
10	Civil Engineering (Construction)	County Antrim, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
11	4D Digital Construction	Greater London, UK	Yes	11.12.17		03.01.18	1	-		-	
12	Construction	Tyne and Wear, UK	Yes	11.12.17		03.01.18		18.01.18		12.02.18	
13	Construction (BIM)	West Yorkshire, UK	Yes	12.12.17		03.01.18		18.01.18		12.02.18	
14	Facilities Services	Berkshire, UK	Yes	12.12.17		03.01.18		18.01.18		12.02.18	
15	Construction	Greater London, UK	Yes	13.12.17		03.01.18	1	-		-	
16	Architecture and Planning	East Sussex, UK	Yes	13.12.17	1	-		18.01.18		-	
17	Construction	Greater London, UK	Yes	13.12.17		03.01.18		18.01.18		12.02.18	
18	Construction	Greater London, UK	Yes	13.12.17		03.01.18		18.01.18		12.02.18	
19	Construction	West Midlands, UK	Yes	13.12.17		03.01.18		18.01.18		12.02.18	
20	Civil Engineering	West Midlands, UK	Yes	12.12.17		03.01.18		18.01.18		12.02.18	
21	Architecture and Planning	West Sussex, UK	Yes	13.12.17		03.01.18		18.01.18		12.02.18	
22	Construction	Greater London, UK	Yes	14.12.17		03.01.18		18.01.18		12.02.18	
23	Construction	Hertfordshire, UK	Yes	15.12.17		03.01.18		18.01.18		12.02.18	

	Companies	Location	Emails sent	Date	Response	Reminder	Response	Reminder	Response	Reminder	Response
24	Architecture and Planning	Nottinghamshire, UK	Yes	15.12.17		03.01.19	1	-		-	
25	Business Supplies and Equipment	West Yorkshire, UK	Yes	15.12.17		03.01.18		18.01.18		12.02.18	
26	Design	Surrey, UK	Yes	13.12.17		03.01.18		18.01.18		12.02.18	
27	Mechanical / Industrial Engineering	Greater London, UK	Yes	15.12.17	1	-		-		-	
28	Construction	Greater London, UK	Yes	15.12.17		03.01.18	1	-		-	
29	Construction	Greater London, UK	Yes	15.12.17		03.01.18		18.01.18		12.02.18	
30	Computer Software	Tyne and Wear, UK	Yes	19.12.17		03.01.18		18.01.18		12.02.18	
31	Management Consulting	Greater London, UK	Yes	19.12.17		03.01.18		18.01.18		12.02.18	
32	Engineering professional services	Greater London, UK	Yes	19.12.17	1	-		-		-	
33	Information Technology Services	Kent, UK	Yes	12.12.17		03.01.18	1	-		-	
34	Civil Engineering (Architecture)	West Midlands, UK	Yes	15.12.17		03.01.18		18.01.18		12.02.18	
35	Civil Engineering	Berkshire, UK	Yes	19.12.17		03.01.18		18.01.18		12.02.18	
36	Facilities Services	West Midlands, UK	Yes	19.12.17	1	-		-		-	
37	Design	West Midlands, UK	Yes	19.12.17		03.01.17	1	-		-	
38	Construction	Bedfordshire, UK	Yes	19.12.17		03.01.18	2	-		-	
39	Construction	Surrey, UK	Yes	19.12.17		03.01.18	1	-		-	
40	Construction	Greater London, UK	Yes	19.12.17		03.01.18		18.01.18	2	-	
41	Construction (4D)	Surrey, UK	Yes	19.12.17		03.01.18	1	-		-	
42	Construction	Hertfordshire, UK	Yes	19.12.17		03.01.18	1	-		12.02.18	
43	Property & Construction Consultants	Oxfordshire, UK	Yes	15.12.17		03.01.18	1	-		12.02.18	
44	Architecture and Planning	West Midlands, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
45	Construction and Infrastructure	Warwickshire, UK	Yes	19.12.17		03.01.18		18.01.18		12.02.18	
46	Construction	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
47	Construction	Hertfordshire, UK	Yes	19.12.17		03.01.18		18.01.18		12.02.18	
48	Transportation/Trucking/Railroad	Buckinghamshire, UK	Yes	20.12.17		03.01.18	2	-		-	
49	Architecture and Planning	East Sussex, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	

	Companies	Location	Emails sent	Date	Response	Reminder	Response	Reminder	Response	Reminder	Response
50	Construction	Cheshire, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
51	Construction	West Midlands, UK	Yes	20.12.17		03.01.18	2	-		-	
52	Survey of buildings	Cambridgeshire, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
53	Home factory planned	Greater London, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
54	Computer Software	West Midlands, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
55	Construction (BIM)	Greater London, UK	Yes	21.12.17		03.01.18	1	-		-	
56	Management Consulting	Essex, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
57	Architecture and Planning	Greater London, UK	Yes	22.12.17		03.01.18		18.01.18		12.02.18	
58	Architecture and Planning	Greater Manchester, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
59	Construction	East Midlands, UK	Yes	19.12.17		03.01.18	1	-		-	
60	Construction Services	Greater London, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
61	Information Technology Services	Greater London, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
62	Commercial Building Contractors	Leicestershire, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
63	Construction	South Yorkshire, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
64	Construction (4D)	Merseyside, UK	Yes	20.12.17		03.01.19		18.01.18		12.02.18	
65	Construction and Development	Derbyshire, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
66	Civil Engineering	Greater London, UK	Yes	20.12.17		03.01.18		18.01.18		12.02.18	
67	Facilities Services	Shropshire, UK	Yes	20.12.17		03.01.18	1	-		-	
68	Construction specification	Tyne and Wear, UK	Yes	27.12.17		03.01.18		18.01.18		12.02.18	
69	Construction (4D)	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
70	Engineering consultancy	Tyne and Wear, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
71	Construction	Greater Manchester, UK	Yes	21.12.17		03.01.18	1	-		-	
72	Computer Software	Essex, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
73	Construction	Warwickshire, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
74	Civil Engineering	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
75	Architecture and Planning	West Midlands, UK	Yes	21.12.17		03.01.18	1	-		-	
76	Civil Engineering	Bristol. UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	

	Companies	Location	Emails sent	Date	Response	Reminder	Response	Reminder	Response	Reminder	Response
77	Construction	Hertfordshire, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
78	Architecture and Planning	Essex, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
79	Architecture and Planning	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
80	Automatic	Surrey, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
81	Construction (BIM)	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
82	Information Technology Services	Berkshire, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
83	Construction Industry	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
84	Construction	West Sussex, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
85	Construction	West Midlands, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
86	Utilities	Hertfordshire, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
87	Integrated Construction Service	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
88	Construction	Stirling and Falkirk, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
89	Management Consulting	West Yorkshire, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
90	Construction (BIM)	Greater London, UK	Yes	21.12.18		03.01.19	1	-		-	
91	Construction	North Yorkshire, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
92	Architecture and Planning	Greater London, UK	Yes	28.12.17	1	-		-		-	
93	Civil Engineering (Electricals)	Leicestershire, UK	Yes	15.12.17	1	-		-		-	
94	Computer Software	Tyne and Wear, UK	Yes	21.12.17		03.01.18		18.01.18	1	-	
95	Construction	Greater London, UK	Yes	21.12.17		03.01.18		18.01.18		12.02.18	
96	Renewables and Environment	Oxfordshire, UK	Yes	21.12.17	1	-		-		-	
97	Construction	Hertfordshire, UK	Yes	22.12.17		03.01.18	1	-		-	
98	Writing and Editing	Greater London, UK	Yes	22.12.17		03.01.18		18.01.18		12.02.18	
99	Construction (BIM)	Lincolnshire, UK	Yes	22.12.18		03.01.18		18.01.18		12.02.18	
100	International Companies in the World	The World (Out of the UK)	Yes	27.12.18		03.01.18	2	18.01.18	2	12.02.18	3
101	University of Wolverhampton	West Midlands, UK	Yes	14.12.17	4	-		-		-	
			Unfamiliar responses		1		4		21		8
			Total:		12		33		26		11
									Final Total:	**82**	

Appendix G: Letters and Validation Feedbacks

No.	Chosen Participant (Old) (# _ ID)	Location	Interview Date	# ID Participant for Validation
1	BIM Manager (#17 ID)	UK, Buckinghamshire	12.11.2018	#6 ID Participant
2	Product Manager/ VDC Specialist (#53 ID)	UK, Greater London	07.11.2018	#5 ID Participant
	New Participant			
3	Information Manager	UK, West Midlands	25.10.2018	#2 ID Participant
4	VDC Specialist	India, Maharashtra	18.10.2018	#1 ID Participant
5	Project Manager	Australia, Western Australia	26.10.2018	#3 ID Participant
6	Senior Consultant	US, California	02.11.2018	#4 ID Participant

Dear (Name), - **Chosen Participant (Old)**

I would appreciate if you would be willing to take a part of the validation of the framework for Dynamic 4D LOD (Level of Detail) which has developed from the initial stage to the current version addressing various aspects of collaborative communications. I would suggest if you could be engaged in live text-chat (e.g. Skype or LinkedIn) at any time that suits you.

Upon your confirmation, I would be able to send you the draft framework with a short description and then we can make arrangements for the text chat.

In addition to above, as follow-up of the survey ("Needs for improvements towards Dynamic 4D Modelling") you might have been involved during the period from to Dec 2017 to Feb 2018. Some of main findings from the survey are here with shared with you as listed below:

1) The most of respondents of the survey are from the high positions in their companies as BIM Managers / BIM Co-ordinators or Project Managers / Architects / Lead Designers with experiences from 10 and over 15 years in the related industry.

2) The companies involved in the survey for CAD / BIM software are predominantly using Autodesk software AutoCAD, Revit and Navisworks (82% to 75% approximately) followed with Synchro Software Ltd. Synchro PRO (52.5%) and as for planning software the most used are Ms Project (29.5%) and Primavera (27.9%).

3) Majority of respondents (65.6%) have been implemented BIM into practice in period from 3-5 years while only 19.7% of them had that practice in period from 1-3 years. Majority of respondents were working on projects where BIM was used at Level 2 (75.4%), Level 1 (50.8%) and Level 0 (29.5%) that reflects to credibility to answers provided in the survey.

4) The most frequent responds were confirming that a 4D BIM was used in projects mainly for communicating the plan to the client and as part of the project planning phase with the same percent of 55.7%, followed by for site logistics/space planning with 47.5% and for Communicating between contractors/subcontractors as 42.6%, while 26.2% of respondents indicated that 4D BIM was used in projects for work package conflict detection and site safety briefings. This indicates that 4D BIM usages are still at the level of planning and for the client presentation purpose where more important purposes of a 4D BIM as communication and future work conflict detection is almost undermined. **However, 87.2% of respondents agree that if a 4D model shows more details it can improve the identification of potential conflicts and clashes and they should have ability to change the details of the 4D directly within the software.**

5) Majority respondents (32.8%) declared that CAD/BIM technicians were responsible for creating 4D models of the projects in their companies while only 21.3% were in opinion that Project planners were responsible. However, in response who should be in future responsible for creating 4D Models, majority respondents indicated that responsibility should be on side of Project Planners (45.9%) followed by 18% of CAD/BIM technicians. It is apartment that in current practise the perception of responsibility of creating 4D models still laying on junior staff of company what in good practise should be avoided and responsibility to be given to the Project Planner. Consequently, the survey further confirms that majority respondents are in opinion that Project planners were responsible for specifying how often the simulation on 4D BIM should show changes to the project.

6) Question related to the time interval of the changes in the simulation in respondents' past experience was indicated in the most of cases (29.5%) as it was every week, followed by changes on monthly base with 14.8% and daily (every day) base with 11.5%. A few respondents have hourly with 4.9%. This could be looked at as the logical expression of the current situation as from another question confirmed that the majority of respondents (87.2%) believe that with a 4D model shows more details the time period between model changes can be further shorten (e.g. less than current weekly bases), and that the system would improve the identification of potential conflicts and clashes.

7) In one question it is indicated that 4D BIM was mostly used (over 55%) in project planning phase but in the other question is not presented that Project Planners are using it but mostly BIM Mangers. That implies the important question what is transpiring on in industry because if 4D BIM as the Project Planning tool is not utilised or partly used by the Project Planers but instead they system became more the Project Manager or BIM manager tool. This might be related to the fact of confusion that Planners trained at Universities are not train with right skills.

8) From question Q19 onwards, the respondents stated that out of 28 listed building task examples, 27 tasks of the Model should show changes on Daily bases period. This response is in the pattern with Q14e were respondents are expecting shortening interval of the changes in a 4D simulation (from current weekly to future daily). Furthermore, responses on Q18i where the majority of respondents believe that a 4D model should have the ability to be changed within a 4D software tool and that increasing details in the model could further shorten time interval of model changes (e.g. hourly).

The overall conclusions of research indicate that:

- If the 4D model shows more details it can improve the identification of potential conflicts and clashes in work process.
- the need for ability to change the details of the 4D directly within the software and
- that 4D Model needs to be updated every day.

Based on survey results obtained, it confirms the needs for 4D dynamic planning and that detail of 4D Model should have ability to be changed within the software what is not the case now.

Kind regards,

BOGDAN BUTKOVIC

Dear (Name), - **New Participant**

Further to our brief chat on LinkedIn I am sending you the email to introduce to you my research. I am a candidate for PhD - Postgraduate Research in Built Environment, specialising on the impact of 4D LOD at the University of Wolverhampton in the UK.

The purpose of the study is to identify the lack of awareness and potential needs for improvements towards Dynamic 4D modelling what will be of benefit to specific the AEC industry sector to better understanding of 4D model use.

I would appreciate if you would be willing to be a part of the validation of the framework for Dynamic 4D LOD which has developed from the initial stage to the current version addressing various aspects of collaborative communications. I would suggest if you could be engaged in live text-chat (e.g. via Skype or LinkedIn) at time that suits you.

Upon your confirmation, I would be able to send you Draft frameworks with short descriptions and then we could make arrangements for a text-chat.

You can have an insight of the survey results:

1) The most of respondents of the survey are from the high positions in their companies as BIM Managers / BIM Co-ordinators or Project Managers / Architects / Lead Designers with experiences from 10 and over 15 years in the related industry.

2) The companies involved in the survey for CAD / BIM software are predominantly using Autodesk software AutoCAD, Revit and Navisworks (82% to 75% approximately) followed with Synchro Software Ltd. Synchro PRO (52.5%) and as for planning software the most used are Ms Project (29.5%) and Primavera (27.9%).

3) Majority of respondents (65.6%) have been implemented BIM into practice in period from 3-5 years while only 19.7% of them had that practice in period from 1-3 years. Majority of respondents were working on projects where BIM was used at Level 2 (75.4%), Level 1 (50.8%) and Level 0 (29.5%) that reflects to credibility to answers provided in the survey

4) The most frequent responds were confirming that a 4D BIM was used in projects mainly for communicating the plan to the client and as part of the project planning phase with the same percent of 55.7%, followed by for site logistics/space planning with 47.5% and for Communicating between contractors/subcontractors as 42.6%, while 26.2% of respondents indicated that 4D BIM was used in projects for work package conflict detection and site safety briefings. This indicates that 4D BIM usages are still at the level of planning and for the client presentation purpose where more important purposes of a 4D BIM as communication and future work conflict detection is almost undermined. **However, 87.2% of respondents agree that if a 4D model shows more details it can improve the identification of potential conflicts and clashes and they should have ability to change the details of the 4D directly within the software.**

5) Majority respondents (32.8%) declared that CAD/BIM technicians were responsible for creating 4D models of the projects in their companies while only 21.3% were in opinion that Project planners were responsible. However, in response who should be in future responsible for creating 4D Models, majority respondents indicated that responsibility should be on side of Project Planners (45.9%) followed by 18% of CAD/BIM technicians. It is apartment that in current practice the perception of responsibility of creating 4D models still laying on junior staff of company what in good practice should be avoided and responsibility to be given to the Project Planner. Consequently, the survey further confirms that majority respondents are in opinion that Project planners were responsible for specifying how often the simulation on 4D BIM should show changes to the project.

6) Question related to the time interval of the changes in the simulation in respondents' past experience was indicated in the most of cases (29.5%) as it was every week, followed by changes on monthly base with 14.8% and daily (every day) base with 11.5%. A few respondents have hourly with 4.9%. This could be looked at as the logical expression of the current situation as from another question confirmed that the majority of respondents (87.2%) believe that with a 4D model shows more details the time period between model changes can be further shorten (e.g. less than current weekly bases), and that the system would improve the identification of potential conflicts and clashes.

7) In one question it is indicated that 4D BIM was mostly used (over 55%) in project planning phase but in the other question is not presented that Project Planners are using it but mostly BIM Mangers. That implies the important question what is transpiring on in industry because if 4D BIM as the Project Planning tool is not utilised or partly used by the Project Planers but instead they system became more the Project Manager or BIM manager tool. This might be related to the fact of confusion that Planners trained at Universities are not train with right skills.

8) From question Q19 onwards, the respondents stated that out of 28 listed building task examples, 27 tasks of the Model should show changes on Daily bases period. This response is in the pattern with Q14e were respondents are expecting shortening interval of the changes in a 4D simulation (from current weekly to future daily). Furthermore, responses on Q18i where the majority of respondents believe that a 4D model should have the ability to be changed within a 4D software tool and that increasing details in the model could further shorten time interval of model changes (e.g. hourly).

The overall conclusions of research indicate that:

- If the 4D model shows more details it can improve the identification of potential conflicts and clashes in work process.
- the need for ability to change the details of the 4D directly within the software and
- that 4D Model needs to be updated every day.

Based on survey results obtained, it confirms the needs for 4D dynamic planning and that detail of 4D Model should have ability to be changed within the software what is not the case now.

Thank you for your willingness to assist this research. We value your participation.

Kind regards,

BOGDAN BUTKOVIC

DRAFT FRAMEWORKS WITH SHORT DESCRIPTIONS

Initially a conceptual framework **(Figure 1)** was created holding together the key elements of existing methods of 4D simulation identified in literature and some of the key issues that would impact on the development of the LOD of 4D simulations (Butkovic and Heesom, 2017). The study presented a framework for creating a more dynamic 4D model by using information from Building Information Modelling. The critical parts of the conceptual framework are the graphical level of detail and various levels of temporal detail. Both graphical and temporal levels of details are influenced by numerous factors crucial for the construction project. The proposed framework emphasizes the necessity for planning, controlling and coordinating construction phases using visualized analysis of conflicts and clashes in models even before construction works.

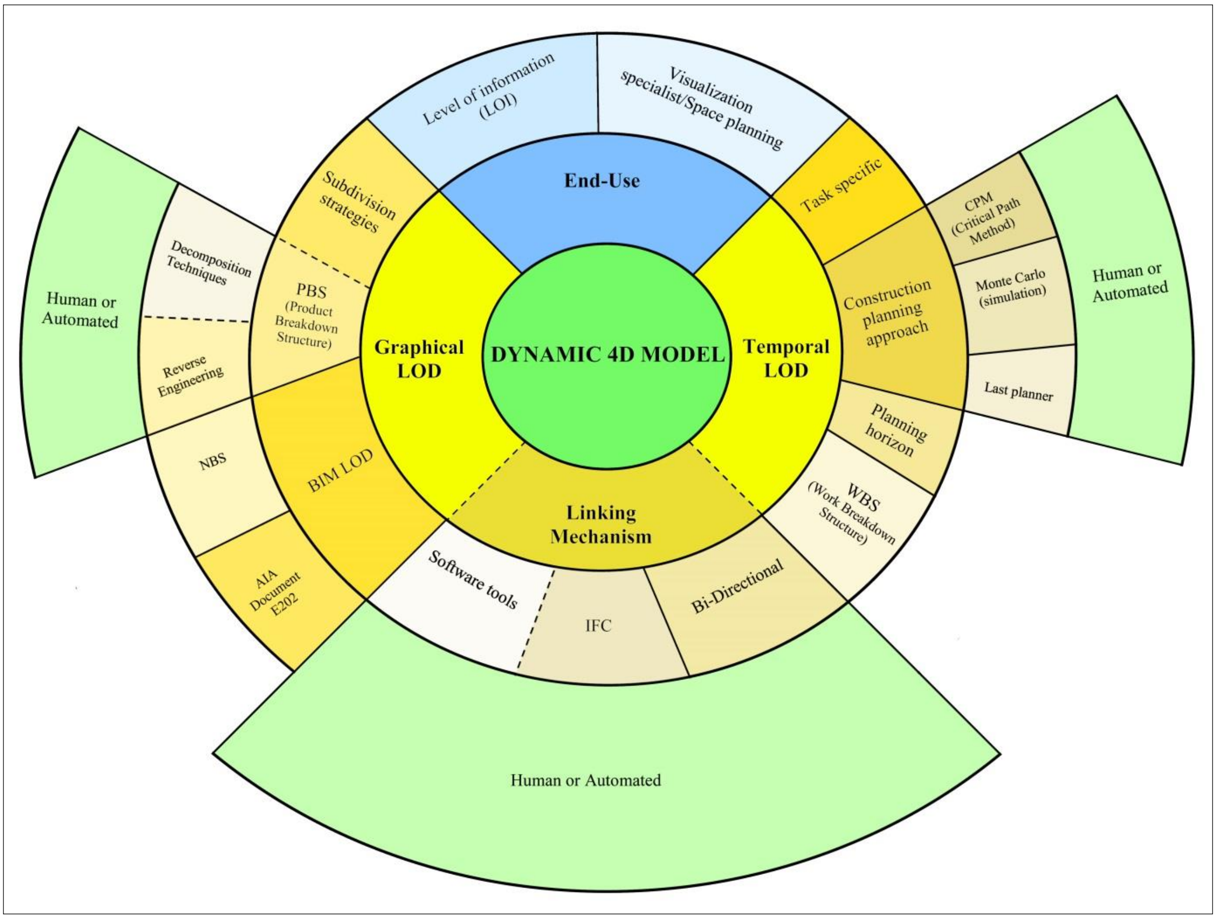


Figure 1: Conceptual framework of Dynamic 4D model (D4DM)

As outcome of questionnaire survey the framework **(Figure 2 in page 3)** was developed. The data received from the questionnaire survey was consisted of a range of professionals who were categorised into those whose specialism was BIM, those who were designers, project planner/management and surveyors. This gave a cross section of those who currently utilise 4D BIM for a range of applications.

The ability to create more ‘realistic’ simulations of the construction process is measured by the capacity to a) view realistic graphical representations of individual objects during construction and b) better control the time between state changes of the 4D model (LODti) which then has an impact on how individual geometric objects from the BIM are subdivided.

The interesting response from the questionnaire noted that the ability to subdivide the geometry to show a more granular level of development in the 4D simulation was beneficial. Linking this to a schedule with a higher level of detail will then provide a more detailed 4D simulation which, from the results, planners see as beneficial during logistics planning of site operations.

The range of software tools to support the development of 4D is still limited, primarily down to the very specific nature of the task and the uses of 4D at the present time are still very much focused on the communication to various stakeholders in the construction process. It is based on the above and building on the initial conceptual framework, the findings from literature and the results of the questionnaire a LOD4d schematic is proposed to provide guidance on how each of the essential LOD factors link and inform some example use cases.

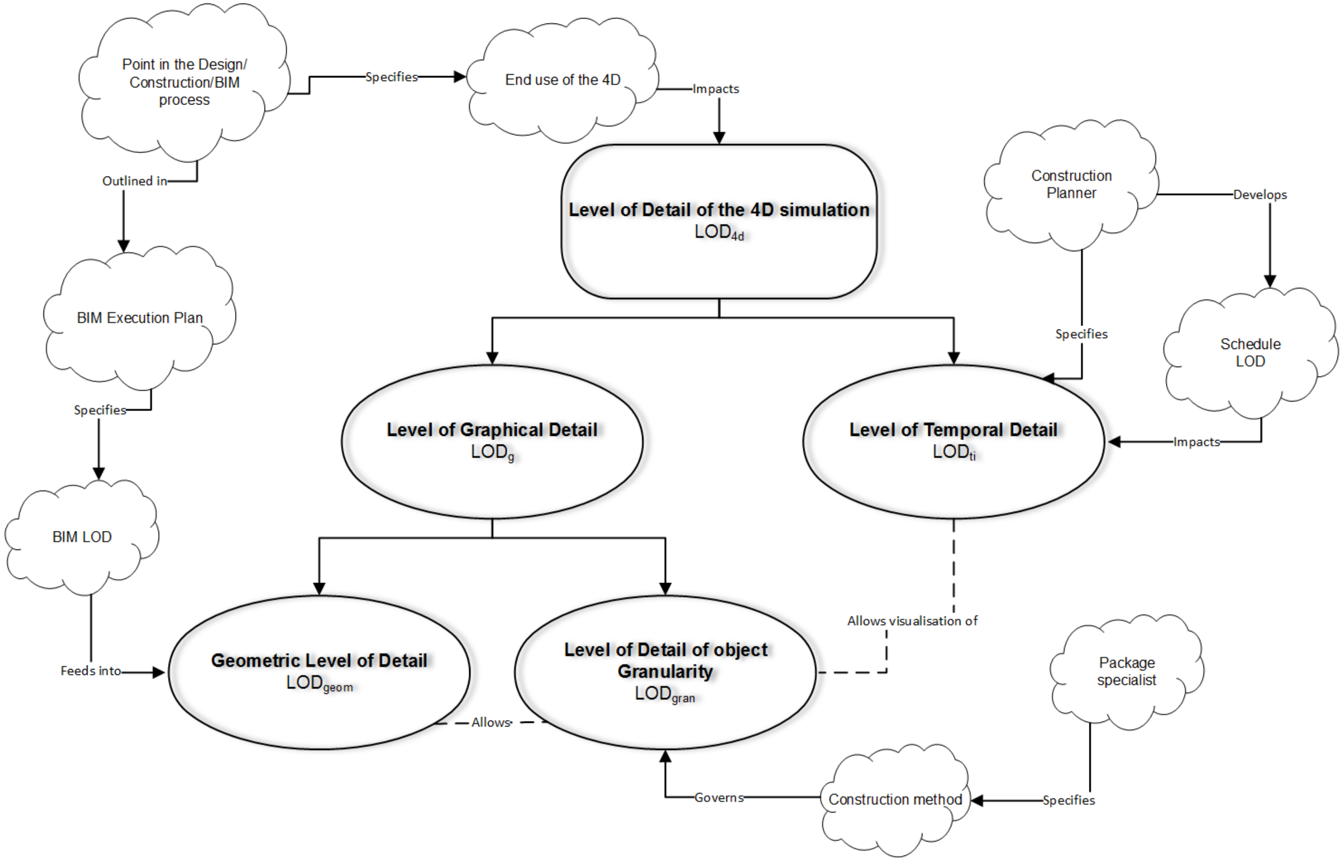


Figure 2: Framework for specifying the LOD of a 4D simulation (LOD4d)

Whilst this approach does provide a theoretical underpinning to undertake this, there are still technological developments to be made to software tools to allow this to happen.

Questions:

- Can you tell me your job title in the company you work for?

1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

3. Does the framework include all the necessary components?

4. Where do you think the level of detail in the 4D simulation should be specified?

5. Do you consider the schedule a level of detail when thinking about a 4D model?

6. How relevant do you think this approach would be to a typical construction project?

7. What do you think, would this framework only be valid on certain construction projects but not others?

8. How might you use that framework on a construction project where you need 4D?

9. How might you improve the framework?

10. What do you think is missing from my framework that needs to be included?

Framework Validation Interviews

#1 ID Particpant – VDC Specialist

OCT 16

Bogdan Butkovic • 1:37 PM
Hi [redacted]

Thank you for accepting me on your LinkedIn but I would like to send you. It is regarding my PhD work as I am working on improving 4D simulation through the Level of Detail (LOD). Let me know if you are interested.

Regards,
Bogdan Butkovic

OCT 17

[redacted] • 9:28 AM
Dear Bogdan,
thank you. I am always interested in 4D & 5D works.
i am interested.
thanks and Regards,
[redacted]

Bogdan Butkovic • 9:37 AM

Bogdan Butkovic • 9:53 AM
Thanks, [redacted]. Please find attached two files. One contains my survey results and second is the file with frameworks I developed. Please look at it and let me know if we can be on live chat as I would have some questions to ask you.

Regards,
Bogdan

PDF Results of the survey .pdf
180 KB

PDF Two Frameworks.pdf
403 KB

[redacted] • 5:34 PM
Hi Bogdan,
ok we will connect tomorrow evening 5 or 6 pm - Indian time, if it is ok for you.
please confirm
Thanks and Regards,
[redacted]

Bogdan Butkovic • 6:09 PM
Thanks [redacted] I will be at that time on LinkedIn for the live text chat. As I am doing my thesis I need to have the whole interview written as a proof. I hope you do not mind me writing the question to you and you give me your written answer? It would take 20-30 minutes maybe even less than that.

Regards,
Bogdan

[redacted] • 7:21 PM
Ok

OCT 18

[redacted] • 1:31 PM
hi

Bogdan Butkovic • 1:31 PM
Hi

[redacted] • 1:32 PM
How are you?

Bogdan Butkovic • 1:32 PM
Fine.

[redacted] • 1:32 PM
ya tell me.

Bogdan Butkovic • 1:32 PM
How are you?

[redacted] • 1:33 PM
I'm good

Bogdan Butkovic • 1:33 PM
First I want to thank you for your time and your good will to help me. I am so grateful. I need to tell that the ethical rules I signed make me obligated not to write your name or the name of the company you work for. I can only write job title. Can we start?

[redacted] • 1:34 PM
ya sure

i am currently working as VDC specialist

(4D & 5D BIM)

Bogdan Butkovic • 1:35 PM
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

[redacted] • 1:40 PM
to a large extent yes.

Bogdan Butkovic • 1:40 PM
2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

[redacted] • 1:44 PM
We are an EPC company. hence we have our own designs designed by our designers (Architects). once the flow diagram is finalized, the models are again divided / reshaped into construction models by planners. the planners will make the L10 level of schedule in primavera and these two will be uploaded into synchro for linking and simulation

Bogdan Butkovic • 1:45 PM
3. Does the framework include all the necessary components?

[redacted] • 1:46 PM
We are an EPC company. hence we have our own designs designed by our designers (Architects). once the flow diagram is finalized, the models are created by designers. these designs are again divided / reshaped into construction models by planners. the planners will make the L10 level of schedule in primavera and these two will be uploaded into synchro for linking and simulation

Bogdan Butkovic • 1:47 PM
4. Where do you think the level of detail in the 4D simulation should be specified?

[redacted] • 1:50 PM
for our initial review (tendering), we use LOD 100 & 200.
after getting the tender, we use LOD 300 & 350 during construction

Bogdan Butkovic • 1:50 PM
5. Do you consider the schedule a level of detail when thinking about a 4D model?

[redacted] • 1:51 PM
since our clients are not requiring As built models. we dont go for LOD 500

Bogdan Butkovic • 1:51 PM
6. How relevant do you think this approach would be to a typical construction project?

[redacted] • 1:51 PM
yes

[redacted] • 1:53 PM
as i said, we do the basic framework first and then create the LOD 300 & LOD 400 Level of 3D model. parallel we create L8 to L10 level of schedule

Bogdan Butkovic • 1:53 PM
7. What do you think, would this framework only be valid on certain construction projects but not others?

[redacted] • 1:55 PM
every construction project is different from other and it requires some adaptation. but in general the framework is very much valid. this creates basic standards

Bogdan Butkovic • 1:55 PM
8. How might you use that framework on a construction project where you need 4D?

[redacted] • 1:59 PM
we are almost following the same framework. we do design the 4D in the same lines

Bogdan Butkovic • 2:00 PM
9. How might you improve the framework?

[redacted] • 2:02 PM
By putting comparability between the softwares..

like navisworks and synchro pro

Bogdan Butkovic • 2:02 PM
10. What do you think is missing from my framework that needs to be included?

[redacted] • 2:04 PM
if i can write...... 5D and 6D

Bogdan Butkovic • 2:05 PM
Okay

Thank you so much and this is a huge help to me. Thank you for your time and your effort. I wish you all the best and if you ever need any similar favour you can count on me.

[redacted] • 2:05 PM
this is perfect for 4D
but cost loading (5D)and stakeholder shares (6D)can be included

thank you

Bogdan Butkovic • 2:06 PM

[redacted] • 2:06 PM
same feeling here as well

thank you

#2 ID Particpant – Information Manager

SEP 28

Bogdan Butkovic • 12:46 PM
Hi [redacted],

Thank you for accepting me on your LinkedIn but I would like to send you an email beginning of next week. It is regarding my PhD work. I am working on improving 4D simulation through the Level of Detail (LOD). Let me know if you are interested.

Regards,

Bogdan Butkovic

[redacted] • 12:52 PM
Hi Bogdan, always interested to hear improvement opportunities.
Address: [redacted]
Regards
[redacted]

Bogdan Butkovic • 12:55 PM

Thank you for things sent to me. Will email you soon. Regards,
Bogdan

OCT 12

Bogdan Butkovic • 2:21 PM
Hi [redacted]

I have been wondering if you have read my email of 30th September? (Needs for improvements towards Dynamic 4D Modelling)

Regards,
Bogdan

[redacted] • 6:27 PM
Not sure I received this. Let me check again.

[redacted] • 6:47 PM
Okay. Just checked I did receive this, thanks. I've had a quick read. It poses many questions. I'm happy to discuss your research by Skype or other means. It may require a couple of sessions, the first session to understand terms such as 'Dynamic', 'Level 2', etc, or if you prefer to meet in person. Let me know.

[redacted].

Bogdan Butkovic • 7:19 PM
Thank you for your message and will email you the draft framework in the PDF document today. Once you see the frameworks we can see how we can do the interview. As I am in Leicester I can visit you in Birmingham.

Regards,
Bogdan

OCT 19

Bogdan Butkovic • 1:56 PM
Hi [redacted],

As I have not heard from you I am sending you some explanations you asked for. (See the file attachment - Dynamic and Level 2 explanations).

I am only asking for 20min of your time on live text chat to ask you some questions. We can do it using LinkedIn chat. As I need a written proof of the interview the live text chat would be the best way to find out about your opinion.

Kind regards,
Bogdan

DOC Dynamic and Level 2 exp...
19 KB

[redacted] • 8:13 PM
Hi Bogdan,

Thank you for the clarification. Excuse any pedantry as I want to ensure our definitions of various terminology are aligned to avoid any ambiguity.
Let's set up an interview next week. I'll try to remember to be in touch on Monday.
Until then have a good weekend.
Regards
[redacted]

Bogdan Butkovic • 8:39 PM
Thanks, [redacted]. I understand that and next week sounds good especially Thursday and Friday. Good weekend to you too.

Regards,
Bogdan

OCT 25

Bogdan Butkovic • 2:00 PM
Hi [redacted],

Would it be possible for us to engage in live text chat today or tomorrow regarding the frameworks I sent to you? I have some questions to ask you and your opinions would mean a lot of in my research study?

Regards,
Bogdan

[redacted] • 4:27 PM
Yes, of course

Bogdan Butkovic • 5:06 PM
Thanks, [redacted]. When is going to be today or tomorrow?

[redacted] • 5:16 PM
I can spare 30 mins now

[redacted] • 5:20 PM
Or 07:30 tomorrow

Bogdan Butkovic • 5:21 PM
Very good. We can do it via LinkedIn as I need written proof of the interview. Tell me when I can send you the first question.

As I need to respect the ethical rules I am not allowed to write your name on my thesis but only your job title. Could you tell me now what your job title is?

[redacted] • 5:24 PM
I'm contracted to provide the following role: Information Manager (BIM)

Bogdan Butkovic • 5:25 PM
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

[redacted] • 5:26 PM
Yes

Can I provide details over the weekend?

Bogdan Butkovic • 5:27 PM
Sorry but it should be now as this count as live interview.

[redacted] • 5:28 PM
Okay

Bogdan Butkovic • 5:28 PM
You can try to think of the most significant things that you see it now.

Bogdan Butkovic • 5:31 PM
Is there anything else you can add to the answer yes?

[redacted] • 5:31 PM
It takes into account the 4D inputs necessary to design a suitable process

Okay ready for Q2

Bogdan Butkovic • 5:32 PM
2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

[redacted] • 5:33 PM
Is there a scale? 1 - no effort 5 - loads of effort?

Bogdan Butkovic • 5:34 PM
No scale

Bogdan Butkovic • 5:36 PM
In your own opinion would it be loads of efforts?

[redacted] • 5:36 PM
The level of effort to implement the framework would be minimal. The level of effort to implement the information within the framework would vary depending on my clients. And would vary from much effort to a great level of effort.

Bogdan Butkovic • 5:36 PM
Do you mean the loads of efforts regarding the labour or technology?

[redacted] • 5:37 PM
Loads of effort ensuring the BIM standards in each segment are met.

Bogdan Butkovic • 5:37 PM
3. Does the framework include all the necessary components?

[redacted] • 5:38 PM
Necessary components, yes. Are there others missing, yes.

You cover the essentials

Bogdan Butkovic • 5:39 PM
4. Where do you think the level of detail in the 4D simulation should be specified?

[redacted] • 5:39 PM
In the EIR

Bogdan Butkovic • 5:41 PM
Please could you tell me what the EIR is?

[redacted] • 5:41 PM
Employers Information Requirements

Bogdan Butkovic • 5:42 PM
Sorry I am not familiar with the abbreviation. Thank you.

5. Do you consider the schedule a level of detail when thinking about a 4D model?

[redacted] • 5:42 PM
Good question

No, well not until Q.5 was asked.

Bogdan Butkovic • 5:44 PM
6. How relevant do you think this approach would be to a typical construction project?

[redacted] • 5:45 PM
Define this approach. Do you mean the framework of Q.5?

Bogdan Butkovic • 5:45 PM
Yes

[redacted] • 5:46 PM
Very relevant

Bogdan Butkovic • 5:46 PM
7. What do you think, would this framework only be valid on certain construction projects but not others?

[redacted] • 5:47 PM
All construction projects where BIM is mandated.

Bogdan Butkovic • 5:48 PM
8. How might you use that framework on a construction project where you need 4D?

[redacted] • 5:49 PM
To help ensure the 4D requirements are considered

Bogdan Butkovic • 5:50 PM
9. How might you improve the framework?

[redacted] • 5:51 PM
Consider CBS (cost breakdown structure) and risk

Bogdan Butkovic • 5:52 PM
10. What do you think is missing from my framework that needs to be included?

[redacted] • 5:52 PM
Refer to A.9

Bogdan Butkovic • 5:53 PM
Thank you so much and this is a huge help to me. Thank you for your time and your effort. I wish you all the best and if you ever need any similar favour you can count on me.

[redacted] • 5:53 PM
A.7 other industries too e.g. manufacturing

Bogdan Butkovic • 5:54 PM
Thanks.

[redacted] • 5:54 PM
Thanks for sharing. This is fascinating work. Stay in touch.

#3 ID Particpant – Project Manager

SEP 27

Bogdan Butkovic • 5:13 PM
Hi [redacted],

Thank you for accepting me on your LinkedIn but I would like to send you an email beginning of next week. It is regarding my PhD work. I am working on improving 4D simulation through the Level of Detail (LOD). Let me know if you are interested.

Regards,

Bogdan Butkovic

[redacted] • 10:50 PM

Bogdan Butkovic • 11:30 PM

Thank you for the prompt responded but in order to contact you by email I need your email address.

[redacted] • 11:45 PM
[redacted]

Cheers

Bogdan Butkovic • 11:45 PM

Thank you.

Needs for improvements towards Dynamic 4D Modelling - Bogdan B.

[redacted]
Reply
Mon 01/10, 04:59
Butkovic, Bogdan

Hi Bogdan,

I am interested in your study and would be willing to support.

Two key comments on your email below:

1 - 4D Planning is just an evolution of the planning process and therefore should be controlled by a professionally qualified Planner. It will engage with a wider audience that more traditional forms of planning (Gantt Chart) but should be controlled by the planner to ensure logic is robust and contractual time obligations are in control; and

2 - Your summary 'Based on survey results obtained, it confirms the needs for 4D dynamic planning and that detail of 4D Model should have ability to be changed within the software what is not the case now.' is incorrect. I use Synchro Pro for my 4D work and i create 4d models that are dynamic and can be changed, updated and levels of detail can be changed within the software platform. This however IS NOT the case in Navisworks Timeliner function.

Good work - I look forward to discussing further.

Kind Regards,

[redacted]

OCT 18

Bogdan Butkovic • 4:11 PM
Hi [redacted],

I am wondering have you seen the file with draft frameworks I sent to you on 1st October? Would it be possible to have a live text chat regarding the framework? I would like to ask you some questions which would help me to validate the framework. Let me know if you agree what time would be good for you?

Regards,
Bogdan

OCT 19

[redacted] • 12:19 PM
Hi Bogdan

v.sorry for delayed response.

can you chat via skype?

cheers
[redacted]

Bogdan Butkovic • 12:44 PM

Bogdan Butkovic • 12:48 PM
Hi [redacted],

Thank you for your message. Yes I can but please can we use the live text chat as for my thesis I need all written proof. I hope this is OK. It would take 20-30 minutes to write some questions to you and also for you to write back. I can be on Skype in 5min if this is OK with you?

Regards,
Bogdan

[redacted] • 1:08 PM
Hi Bogdan

I cant this evening. It is 20:08pm here. maybe during the week next week sometime is that ok?

Bogdan Butkovic • 1:12 PM
Hi [redacted],

No problems and yes next week is fine. Thank you.

Regards,
Bogdan

OCT 26

Bogdan Butkovic • 6:50 AM
Hi [redacted],

Hope you remember our communication from last week. You agreed to participate in my doctoral framework validation. Is this good time for you to spare 20-30 minutes engaging in live text chat with me? I have some questions about the framework and your opinion would be highly appreciated.

.
Regards,
Bogdan

[redacted] • 7:52 AM
How about now?

Bogdan Butkovic • 7:55 AM
Now is good.

[redacted] • 7:56 AM
Ok - will I dial in to somewhere or just text on LinkedIn?

Bogdan Butkovic • 7:57 AM
Text on LinkedIn.

[redacted] • 7:58 AM
Ok....

Bogdan Butkovic • 7:58 AM
Good afternoon to you although it is morning in the UK.

[redacted] • 8:00 AM
Good morning Bogdon

Firstly good work on your venture into 4D..it is very interesting and exciting

Bogdan Butkovic • 8:00 AM
As I need to respect the ethical rules I am not allowed to write your name on my thesis but only job title. Could you tell me now what your job title is?

Thank you.

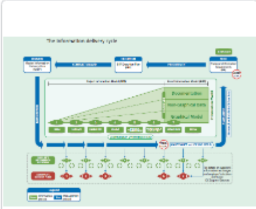
[redacted] • 8:01 AM
I am the Director of [redacted]
) and I am also a Project Manager for Resolute Mining.

Bogdan Butkovic • 8:03 AM
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

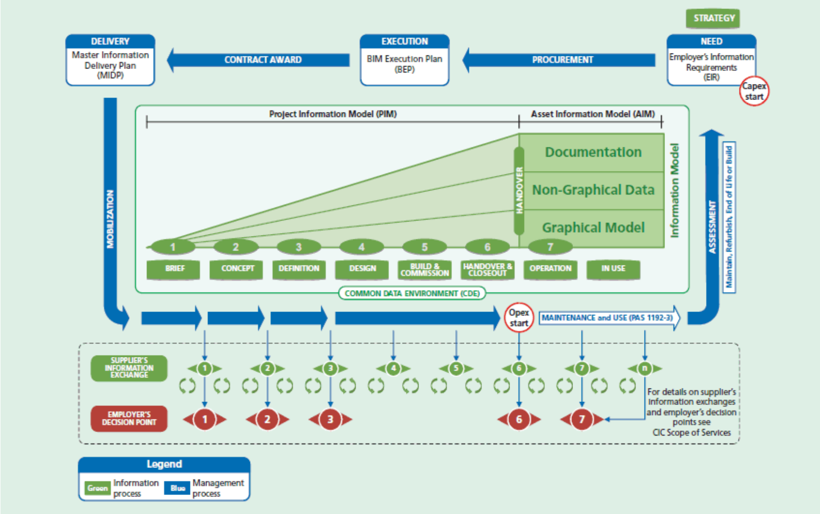
[redacted] • 8:07 AM
I think it is a good start, however perhaps more consideration could be given to how the 4D programme will be developed with other project deliverables and design development. A good way of doing this could be referencing LOD of 4D to the various stages set out in PAS1192.

Bogdan Butkovic • 8:07 AM
2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

[redacted] • 8:09 AM
As it stands, the majority of companies are not equipped to readily produce 4D Planning to any degree of detail. In terms of 'Level of Effort' I think a dedicated resource should be assigned to implementation of 4D and this role should be by someone who has a thorough knowledge of planning and project controls.



The information delivery cycle



Bogdan Butkovic • 8:10 AM
3. Does the framework include all the necessary components?

[redacted] • 8:16 AM
I think this framework is helpful, however there are some fundamental steps that need to be considered before starting to finalise a framework for implementation. Firstly and foremost is 'WHY??'. Why are we choosing to do 4D BIM and what do we want to get out of it? for example if the answer is to visualise a particular high risk component of works in a detailed and complex project, then the schedule will need to be very detailed, but the 3d model geometry and non-geometric data within the model may only need to be very high level and conceptual.

Reference within the framework could be made to various levels of schedule (See PMI-SP documentation) and the level of WBS (Work Breakdown Structure)

Bogdan Butkovic • 8:18 AM
4. Where do you think the level of detail in the 4D simulation should be specified?

[redacted] • 8:19 AM
In the BIM Execution Plan and maybe at high level in the EIR.

Bogdan Butkovic • 8:19 AM
5. Do you consider the schedule a level of detail when thinking about a 4D model?

[redacted] • 8:22 AM
Definitely. Often the planner (4D Planner) is forced to further increase the level of detail within the schedule to create the 4D model as the detail in a 3D model dictates how much detail you need in the schedule to 'assign' all model resources, but i see this as a big benefit and a way of encouraging more detailed planning. On every single 4D project I have been a part of, I have had to further develop the detail of the schedule.

Bogdan Butkovic • 8:23 AM
6. How relevant do you think this approach would be to a typical construction project?

[redacted] • 8:25 AM
It is not relevant to a 'Typical' construction project....yet.

Here in Australia BIM is becoming more frequently used however the adoption of 4D planning is minimal. Most project teams wouldnt be able to understand the framework as the average knowledge of 4D BIM is limited.

Bogdan Butkovic • 8:25 AM
7. What do you think, would this framework only be valid on certain construction projects but not others?

[redacted] • 8:28 AM
I think so, yes. Ultimately BIM adoption is still driven by budget. Simply put, there is not the availability of 4D Planners required to implement 4D on most projects. Additionally, 3D models do not exist on most projects still here in Australia.

Bogdan Butkovic • 8:29 AM
8. How might you use that framework on a construction project where you need 4D?

[redacted] • 8:31 AM
I think your framework is a very good method of helping a team de-mystify how 4D should fit in to the bigger picture BIM delivery. I think it would have to be further refined on a 'case-by-case' basis depending on the particular project requirements. I know more than anybody that clearly defining the scope of 4D is ABSOLUTELY critical as the level of effort (and cost) in producing various levels of detail and application in the 4D process is significant.

Bogdan Butkovic • 8:32 AM
9. How might you improve the framework?

[redacted] • 8:35 AM
An LOD can be referenced for model LOD, however I havent yet seen a document that outlines 4D schedule LOD. This could be a very good idea.

Potential some form of high level guidance of what would be expected for various levels of detail in the schedule would be good to support the framework?!

[redacted] • 8:36 AM
I would also somehow look to include where in the project lifecycle things happen. For example is the 4d implemented at initiation, design development phases or when the contractor is on board for solely construction processes.

Page 3 of 3

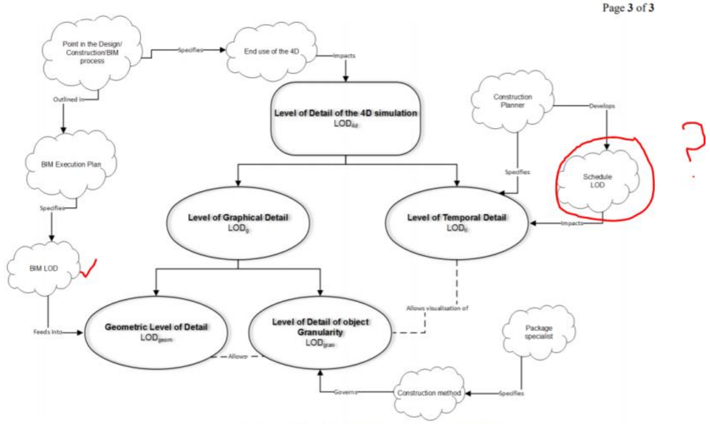


Figure 2: Framework for specifying the LOD of a 4D simulation (LOD4d)

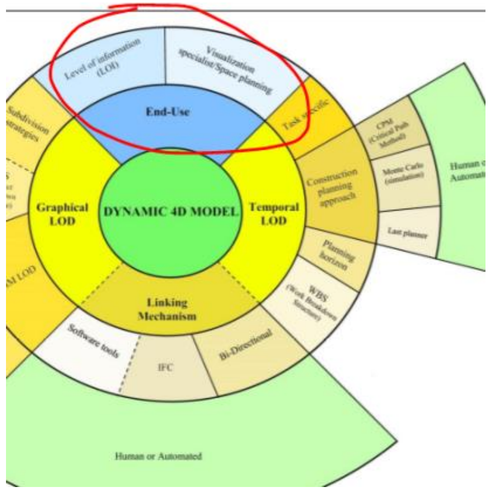
Bogdan Butkovic • 8:38 AM
10. What do you think is missing from my framework that needs to be included?

[redacted] • 8:42 AM
I think as a high level framework this is good Bogdon. I think generally you must always assume that the reader has little understanding of 4D and one way of helping understand a framework or procedure is images. Maybe include some images of the schedules/models/4D models etc..

Bogdan Butkovic • 8:43 AM
That was all. Thank you [redacted] for your time and good will to be a part of my project. This is a huge help as your answers are so clear and I appreciate your understanding and effort. If you ever need similar favour you can count on me. Have a good rest of the day.

[redacted] • 8:43 AM
Perhaps you are missing something about safety in this document also...
maybe somewhere in here:

Thank you Bogdon. Keep me informed with how you go in your studies, i am interested. If ever you want to explore 4D opportunities in Australia you let me know



Bogdan Butkovic • 8:46 AM
Thanks for suggestions I will considerate as the framework needs to be updated after the validation.

Bogdan Butkovic • 8:47 AM
And I will keep you informed as this is the final chapter of my work and who knows Australia could be something I think about after my thesis are done.

#4 ID Particpant – Senior Consultant

OCT 16

Bogdan Butkovic • 3:13 PM
Hi [redacted],

Thank you for accepting me on your LinkedIn but I would like to send you. It is regarding my PhD work as I am working on improving 4D simulation through the Level of Detail (LOD). Let me know if you are interested.

Regards,
Bogdan Butkovic

[redacted] • 10:59 PM
Hi Bogdan, I'm not sure I understand. Is there any way I can help?

OCT 17

Bogdan Butkovic • 6:02 AM
Hi [redacted],

I need practicionars to assist me in the validation of the frameworks I developed. I did a survey on use of 4D technology and as the information I have survey results and the framework which you would need to see it in order for you to answer some questions, of course if you are interested to participate. This is why I contacted you.

Bogdan Butkovic • 6:34 PM
Sorry to confuse you, [redacted]. I am a PhD candidate as I am working on improving 4D technology by enhancing levels of detail - graphical and temporal. I have done the survey in this regard. and developed some frameworks. Now I need help in validating the frameworks. If you are interested in all this let me know I can send you two files you can look at and then I would have some questions to ask you.

Kind Regards,
Bogdan

OCT 26

[redacted] • 7:38 PM
Hey Bogdan, sorry for late reply as I've been quite busy. I'd love to take a look at your frameworks and provide my opinion if you are still looking.

Bogdan Butkovic • 7:53 PM
Thank you so much, [redacted] and yes I am still very much looking for people who would help in the framework validation. . I enclose here two files in the PDF document:

I did some survey on the subject by questionnaire. I enclosed here the survey results and I developed two frameworks one based on the literature review and second framework is an update after the survey analyses. Please look at it and let me know when I can I ask you about your opinion.

Regards,
Bogdan

PDF Results of the survey .pdf
180 KB

PDF Two Frameworks.pdf
403 KB

NOV 1

Bogdan Butkovic • 12:23 PM
Hi [redacted]

Have you had any time to look the framework file I sent you last Friday? Are you still interested to assist me with the framework validation?

Regards,
Bogdan

[redacted] • 2:53 PM
Hello Bogdan, I haven't had time yet but I okayi'm on getting to it soon.

NOV 2

Bogdan Butkovic • 1:49 PM

[redacted] • 3:28 PM
Hi

I reviewed the two documents

The survey results are very interesting

did it mention how many people responded in total? or did I miss that?

The frameworks are interesting too, but the first one is really hard to understand

The second one is insightful, but it could use more elaboration on how is it derived from (or related to) survey results

there is also one thing to mention when it comes to object LOD

actually I'm not sure you are interested into going into more depth

but for example, you can have more geometry and less practical value

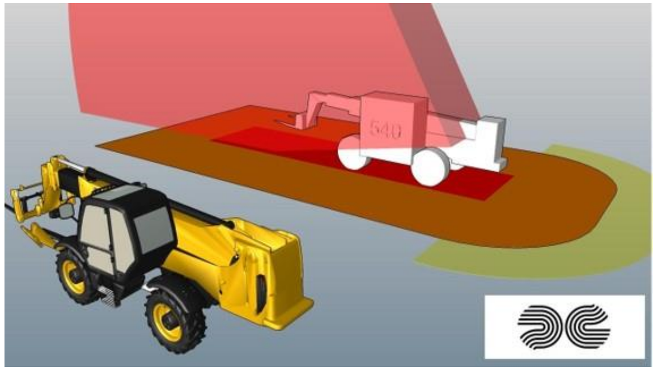
[redacted] • 3:33 PM
the following graphic by [redacted] & [redacted] illustrates my point

Bogdan Butkovic • 3:33 PM
Hi

Thank you so much for this but my question to you would it be possible for you to answer some questions?

[redacted] • 3:34 PM

sure



Bogdan Butkovic • 3:34 PM
My work is to validate my framework and I need to ask the industry practitioners some questions via live text chat

[redacted] • 3:35 PM
sure

Bogdan Butkovic • 3:36 PM

I want to thank you for your time and for the willingness to assist me. I appreciate that. As I need to respect the ethical rules I am not allowed to write your name on my thesis but only your job title. Could you tell me now what your job title is?

[redacted] • 3:37 PM
Senior Consultant

Bogdan Butkovic • 3:37 PM
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

[redacted] • 3:39 PM
yes, but it only a start

Bogdan Butkovic • 3:40 PM
Can you be more specific?

[redacted] • 3:40 PM
actually for a good number of our clients, this is all they need

but we get a biased sample as the companies that hire our services are pretty advanced in the practice

Bogdan Butkovic • 3:41 PM
2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

[redacted] • 3:42 PM
this is a great question, but I'm not sure it applies

what my company does is two things mainly

sell software

and sell consulting services

the second part is more interesting to you maybe

in the consulting services we work with companies already using 4D to make them more efficient

This is a question more for contractors and PM firms

Bogdan Butkovic • 3:45 PM
Ok

[redacted] • 3:46 PM
the framework is great!

Bogdan Butkovic • 3:46 PM
3. Does the framework include all the necessary components?

[redacted] • 3:46 PM
Yes

Bogdan Butkovic • 3:47 PM
4. Where do you think the level of detail in the 4D simulation should be specified?

[redacted] • 3:49 PM
I've seen good and bad results in Contract Specs or BIM execution plan

Contract specs is better as it forces more buy in...

but sometimes it gets bad because they focus too much on just abiding to contract and less on getting actual value

BIM execution plan is more flexible but sometimes will get less buy in from different parties over the course of the project

Bogdan Butkovic • 3:52 PM
5. Do you consider the schedule a level of detail when thinking about a 4D model?

[redacted] • 3:53 PM
Yes, absolutely, however if the schedule is more detailed than needed, you do not have to make any changes because you can use parent tasks as drivers of 4D visualization when needed

if the schedule is less detailed than needed, then activities have to be added when building the 4D

Bogdan Butkovic • 3:54 PM
6. How relevant do you think this approach would be to a typical construction project?

[redacted] • 3:55 PM
Very relevant

Bogdan Butkovic • 3:56 PM
7. What do you think, would this framework only be valid on certain construction projects but not others?

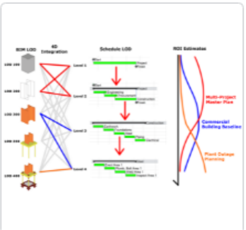
[redacted] • 3:56 PM
I think it is valid on all, but on the more complex projects it is not enough

the projects I'm struggling with now, are the ones that do not discuss what I relayed in the graphic I sent

[redacted] • 3:58 PM
these projects are fewer in quantity, but each project is in the 10s of billions

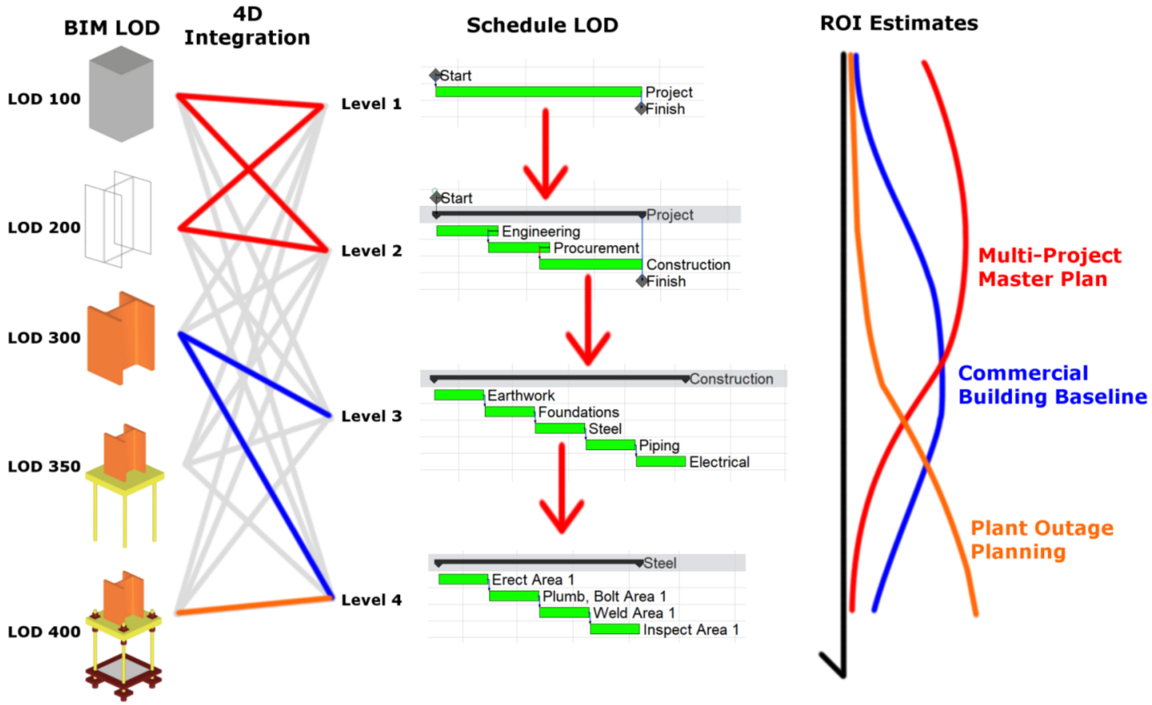
Bogdan Butkovic • 3:58 PM
8. How might you use that framework on a construction project where you need 4D?

[redacted] • 4:00 PM



here's a graphic I produced for a client once

Bogdan Butkovic • 4:01 PM
Thank you



[redacted] • 4:01 PM
you use the point in construction that is mentioned in your framework to determine the LOD combination that gives highest ROI

then you follow the rest of the framework

Bogdan Butkovic • 4:02 PM
9. How might you improve the framework?

[redacted] • 4:06 PM
you split LOD into graphical and time, where is really should be Model and time, and then model should be split to geometry detail, parameters/data, and functional visualizations (crane reach, caution area, etc.)

Bogdan Butkovic • 4:07 PM
10. What do you think is missing from my framework that needs to be included?

[redacted] • 4:07 PM
same as above

Bogdan Butkovic • 4:08 PM
Thank you [redacted] for your time and all the answers. The survey included 101 participants and 61 was completed and included in analyses. Now I do the framework validation doing this kind of interviews in order to improve the framework further. Do you have any question?

[redacted] • 4:08 PM
nope good luck Bogdan!

Bogdan Butkovic • 4:09 PM
Thank you

#5 ID Particpant – Product Manager/VDC Specialist

SEP 28

Bogdan Butkovic • 7:33 PM
Hi [redacted]

I hope you are doing well. I would like to send you the survey results but your email address is changed so could please give me the new address if you are still interested to know my findings?

Regards,

Bogdan

OCT 1

[redacted] • 8:46 AM
Hi Bogdan,
My emails hasn't changed, we are still using synchro domain after aquisition.
Yes, I would love to see your findings (or the entire dissertation if you would like to share).
You can try any of those two:
[redacted]

Regards,
[redacted]

Bogdan Butkovic • 9:04 AM

Bogdan Butkovic • 9:05 AM
Hi [redacted]

Thank you very much for your message and will email you today.

Regards,
Bogdan

OCT 25

Bogdan Butkovic • 1:32 PM
Hi [redacted]

I hope you are well and I was wondering if you have seen my survey results that I emailed you on 1st Oct? Would you like me to send you the attachment of two frameworks in the PDF document to you via LinkedIn? Thank you.

Regards,
Bogdan

OCT 25

Bogdan Butkovic • 1:32 PM
Hi [redacted]

I hope you are well and I was wondering if you have seen my survey results that I emailed you on 1st Oct? Would you like me to send you the attachment of two frameworks in the PDF document to you via LinkedIn? Thank you.

Regards,
Bogdan

[redacted] • 12:00 PM
Hi Bogdan,

There is a several things I've done and haven't done since your initial contact. Please forgive me for taking that long to reply.

You hit possibly the worst timing, as the month October for me was virtually NOT in the calendar. I had several travels and been working offline, then I was attending the week-long conference (YII), after which I had to take a time off due to my health problems.

Today is my first day in the office since the beginning of October, so apologies for having the moment to support your initiative.

I still wanted to study your framework and provide with comments, if it's not too late. Please let me know, and I will spend some time this evening reviewing (what I already read several times, but haven't responded).

Regards,
[redacted]

Bogdan Butkovic • 12:15 PM
Hi [redacted]

Sorry for having health problems as health is the most important for each of us. I did not know that October is so hectic time in your case so I apology for it. It is just that my study is getting to its last stage and I am trying to do my best in order to complete the doctoral thesis and submit my work till the end of this year.

However, I am doing the interviews only this week till Friday 9th October and I am enclosing here my frameworks which I need to validate. If you see it and still interested for do the interview (if you find any free slot in your time till this coming Friday) let me know. So far the interviews were lasting 30min via Skype or LinkedIn live text chat.

Regards,
Bogdan

PDF Two Frameworks.pdf
403 KB

[redacted] • 12:17 PM
We can schedule one this week. What day and time suits you?

Bogdan Butkovic • 12:20 PM
As you are the one occupied with so many things please you choose the time and I will fit in it.

[redacted] • 12:23 PM
All times London zone:
- Wednesday from 9am to 2pm
- Thursday from 9am to 3pm
- Friday from 9am to noon
Pick one and I will send the Outlook reminder

Bogdan Butkovic • 12:30 PM
Thank you, [redacted] Wednesday at 9am sounds good to me. Is it going to be Skype or LinkedIn?

[redacted] • 12:38 PM
Let's do skype call. My user name is "[redacted]"

Bogdan Butkovic • 12:47 PM
Thanks for the Skype address, sent you an invitation. For my thesis I need a written record of the interview so Uni expect me to do live Skype text chat. I hope this is OK with you. I will only ask you some questions regarding the frameworks I have just sent to you.

[redacted] • 1:01 PM
No problem, speak on Wednesday

Wednesday

09:03
Good morning [redacted] How are you?

[redacted], 09:07
Hey Bogdan

all good thank you

09:07
Thank you for accepting my invitation to do the interview.

[redacted], 09:07
how is your work coming together?

09:08
I think I am doing Ok.

Can we start?

[redacted], 09:08
do you want to talk or type?

09:09
Type in this Skype.

The University asks me to have a written record of the interview so let us engage in live text chat.

[redacted] 09:09
no problem, I understand you need transcript

09:09
Good.
Have you seen my draft frameworks that I sent you?

[redacted] 09:10
yes

09:10
Good.

[redacted] 09:10
and I have some reflections / comments on a few things

09:10
Can you tell me your job title in the company you work for?

[redacted] 09:11
Currently, it is a Product Manager, but I was VDC Specialists before that

09:12
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

[redacted] 09:14
I would say "yes", but I would like to make certain distinction. As software vendor, we are provider of BIM technology, not the receiver.
I also have some comments to the framework itself
let's proceed

09:16
I need to ask that too coz I have to update the framework as well

[redacted] 09:16
OK

09:16
2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

[redacted] 09:16
let me look at the iconographic
2. Very little effort, as many of the framework concepts, already exist and are established implemented (where they are implemented)
effort required would be to shift a few elements around or reinforce some parts
for companies, which are not BIM ready at all, or at lower levels of implementation, the effort will be significantly larger
this is due to the fact that AEC industry is not BIM matured equally / evenly

09:20
3. Does the framework include all the necessary components?

[redacted] 09:22
I am referring to D4DM - I am not sure the full extent of the framework (cannot see the big picture from just the Figure 1. iconography)
I think, it is comprehensive, although it misses several important elements
and some proposed elements are actually contradicting the idea of Dynamic 4D

09:24
4. Where do you think the level of detail in the 4D simulation should be specified?

[redacted] 09:24
early into the design/engineering
the earlier the better

09:25
5. Do you consider the schedule a level of detail when thinking about a 4D model?

[redacted] 09:25
depending what planning method is used
there are particularly two methods, when you think about 4D approach
one is traditional - integration of schedule and model
the other one is BIM-oriented - model-based planning method
in the first case, the LOD is ALWAYS a consideration (and also a significant problem)
in the second case, the LOD is implied and the problem is solved with use of this method

09:28
Thank you
6. How relevant do you think this approach would be to a typical construction project?

[redacted] 09:29
you mean D4DM?

09:29
Yes

[redacted] 09:29
and please clarify what do you mean by "construction project"?
in the UK, construction means "buildings"
if you think broader, the construction will be ANY project, building, infra etc.
which one you think?

09:31
The project that is BIM oriented.

[redacted] 09:31
OK

09:31
Yes any.

[redacted] 09:32
the framework will be relevant for ANY project using BIM, some industries will see larger relevance (and benefit) - for example, buildings, single location projects

09:33
7. What do you think, would this framework only be valid on certain construction projects but not others?

[redacted] 09:34
as previously - it will be valid on any project, when 4D is specified

09:34
8. How might you use that framework on a construction project where you need 4D?

[redacted] 09:35
I would use it to change the methods of planning and scheduling
and specify the requirement for 4D more clearly, to gain measurable benefits

09:37
9. How might you improve the framework?

[redacted] 09:38
OK, on this, I could probably spend half a day 🙂
as I said at the beginning, I see some elements of the framework are in direct contradiction to "dynamic 4D"
the use of some elements is unclear

09:40
I know you do not have that much time but anything you think that is the most important.
Yes that is what I wanted to ask you at the end

[redacted] 09:41
let's do Q9. now

09:41
Ok

[redacted] 09:41
I will try
a) CPM (Critical Path Method) is in a direct contradiction to the idea of "dynamic" 4D
we are trying to change it, remove CPM from the 4D process
CPM is consider a "legacy" planning method and its association with 4D is "killing" understanding of what 4D is trying to change in the indistry
Construction Planning Approach, should focus on Resources, Resource Dependencies and Resource oriented planning methods

this also should be supplemented by "spacial awareness"

introduction of "location" resource

workspace planning

etc.

the dynamic 4D should therefore:

- remove CPM from the planning process

- introduce the idea of spacial awareness / spacial coordination (e.g. 2 people, 1 crane are occupying THAT space for certain time and that is a Resource Constraint, etc)

- CPM should be replaced by Model-Based Planning method, which also removes hurdles of some other problems (fro example, also mentioned in the framework - Linking Mechanism)

b) Linking Mechanism - this should NOT exist at all

in other words - framework should assume automatic (or user controlled) rapid generation of schedule

based on geometry (or work package)

and resource driven calculation (e.g. duration, constraints)

c) sequence (or modular sequence) should also be generative - on other words, WBS should take over that role

futher to that

WBS (or sequence), should reply on intelligent data from BIM

but currently, WBS generation is (in 90%) cases driven by the cost managers / accountants

d) what is "Visualisation specialist" role? Is it the presentation layer? Holywood-BIM?

and if that is the meaning, what "space planning" doing in the same part of framework

space planning, as I mentioned earlier should be in the planning domain, in the resource-driven planning method, replacing CPM

e) I think "Graphical LOD" part is good

but "Temporal LOD" part would require some re-thinking

I believe (and people like me are trying to change this the industry), the whole problem with 4D is with the "planning domain"

unfortunately this framework will contribute to further sustain "planning problems" by even mentioning CPM

and assuming, other method are introduced (not-CPM) making the 4D truly dynamic, Linking Mechanism is not relevant . not needed

10:01

This is why I am doing the interviews.

[redacted] 10:01

i think that:s it

10:01

All you said would be included in my final work.

I needed opinions from industry practitioners.

[redacted] 10:01

again, this is my observation and I am objective in my assessment

it is not opinion really

10:02

Ok

[redacted] 10:02

it's backed by empirical observations

10:02

Good.

[redacted] 10:02

information for you - I am also a sociologists

10:03

I need to consider all the idea you wrote here. I was looking at the framework while you were explaining things and I was getting what you were saying.

10:03

Thank you for the info.

[redacted] 10:03

OK

no problem

10?

10:04

Yes.

10. What do you think is missing from my framework that needs to be included?

[redacted] 10:04

a) Model-based planing & scheduling

b) Resource-driven dependencies (which is kind of mentioned as "last planner"

c) spacial coordination / workspace & work interface planning

all in the Temporal LOD domain

you actually have spacial planning

but it is in the wrong Domain

what is not missing really, but should be changed slightly

is the WBS

I would add new element behind WBS

wait a minute I will draw it

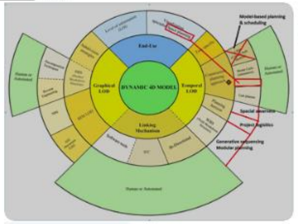
10:08

Thank you.

[redacted] 10:08

will be easier

[redacted] 10:16



something like this

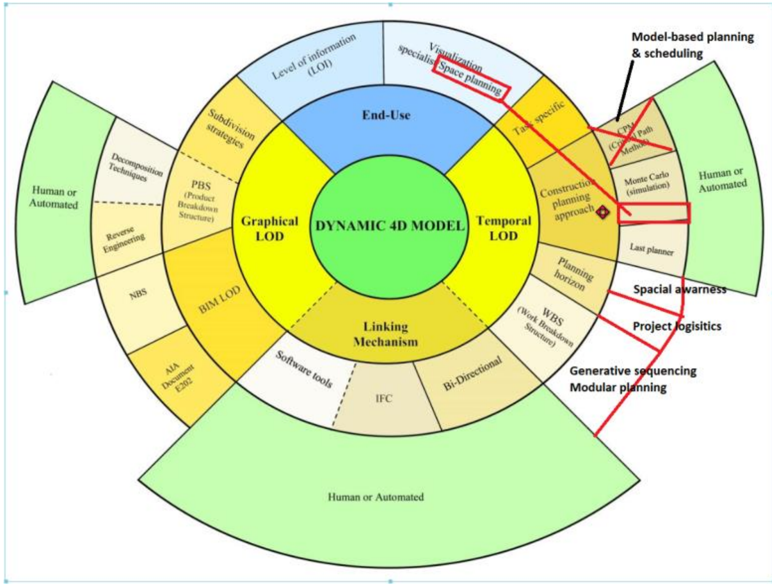
and of course this is just my view on this

new elements are Spacial Awarness, Project Logistics

and Generative sequencing

10:18

Let me see it.



[redacted] 10:18

Spacial Planning should really be in Construction Planning

as this is INBOUND data

not OUTBOUND

I would leave Linking Mechanism

but you know my comments around it

also

10:20

Thank you for the image you sent.

[redacted] 10:20

all good

you can use the concepts

or not

it is your work

but the biggest issue is with CPM

10:21

I got that. That is all.

Thank you for your detailed answers and all the suggestions. This is really tremendous help to me. I am so grateful. I will certainly consider all the suggestions. Thank you so much for your time.

[redacted] 10:21

that is no problem at all

happy to be able to contribute 2 cents to your research

10:22

Have a good day [redacted] Thank you.

I appreciate.

[redacted] 10:22

same to you Bogdan

#6 ID Particpant – BIM Manager

From: [redacted] Barry <Barry.Gleeson@networkrail.co.uk>
Sent: 17 October 2018 14:06
To: Butkovic, Bogdan
Cc: [redacted]
Subject: RE: Needs for improvements towards Dynamic 4D Modelling

Hi Bogdan,

Apologies I haven't responded earlier but I have been out of work from nearly a month do to family needs.

I have cc'd some of my team and an NR specialist on 4D modelling.

I would be grateful if you could confirm your outline background and the project sponsors and what this will be used for, for the benefit of those cc'd in. We will try to respond to yoru collective and engage others if it helps provide a more rounded response for NR as a client.

Kind regards

[redacted]

From: Butkovic, Bogdan
Sent: 17 October 2018 14:40
To: [redacted]
Cc: [redacted]
Subject: Draft frameworks with short descriptions

Hi [redacted]

Thank you for your email and for including more people as I really need help. As a reminder to you: I did a questionnaire in December last year regarding my PhD thesis. I am working on the importance of LOD for a 4D simulation. You were one of my participants and as you requested the results of the survey I sent it to you the results in the previous email (30th Sept.).

I am sending you now the frameworks I developed and I would need a help in the framework validation. **(Attachment - Two Frameworks in the PDF document)**. If you or any of your colleagues are interested to answer my questionnaires during a live text chat (LinkedIn or Skype) that would be a tremendous help. I am suggesting the text chat as I need written answers for my University work.

Regards,

Bogdan Butkovic

BB Butkovic, Bogdan
Mon 05/11, 09:27
Reply
[redacted]

Hi [redacted]

Hope you are well. I am wondering if there is still interest from your side in validating my framework? Please let me know.

King Regards,

Bogdan Butkovic

From: Butkovic, Bogdan
Sent: 25 October 2018 12:45
To: [redacted]
Cc: [redacted]
Subject: Re: Draft frameworks with short descriptions

Hi [redacted]

I hope all is well with you. I have not heard from you since 17th October (Wed). Is there any possibility we can be engaged in live text chat today or tomorrow via LinkedIn or Skype? It would take 20min of your time. I have some questions regarding my framework and it would mean a lot to me and my work on the doctoral thesis?

Regards,

Bogdan

[redacted]

Mon 05/11, 10:59

Hi Bogdan,

Interest of course, time a problem.

As those CC'd were not involved in the early development I think they won't have time to pick this up now. My own time is also extremely pressed lately.

So what's your latest date for a response and I'll let you know what I can do.

Kind regards

[redacted]

From: Butkovic, Bogdan
Sent: 05 November 2018 11:09:47
To: [redacted]
Subject: Re: Draft frameworks with short descriptions

Thank you for the respond, [redacted]. This coming Friday is the deadline for me to complete interviews so I can work on the discussion parts for my thesis. Is there any day till the end of the week to spare 30min on Skype live text chat?

Regards,

Bogdan

From: Butkovic, Bogdan
Sent: 09 November 2018 09:43
To: [redacted]
Subject: Re: Draft frameworks with short descriptions

Hi [redacted]

I am sorry I did not respond earlier. My latest date for the interview is 13th November as am given one month to complete the validation interviews. Is there any chance we can engage in live text chat over Skype? I know you said you are very busy but this does not take much time and it would mean a huge help.

Regards,
Bogdan

From: Butkovic, Bogdan [mailto:B.Butkovic@wlv.ac.uk]
Sent: 12 November 2018 13:12
To: [redacted]
Subject: Re: Draft frameworks with short descriptions

Hi [redacted]

Just to let you know that my supervisors gave me this whole week to use for the interview and I hope you can have time for a live text chat. Only Wednesday this week is not good for me as I will spend the most of my day on travelling. Please let me know if you have any spare time?

Kind Regards,

Bogdan Butkovic

From: [redacted]
Sent: 12 November 2018 13:32
To: Butkovic, Bogdan
Cc: [redacted]
Subject: RE: Draft frameworks with short descriptions

Hi Bogdan,

Apologies for the late reply – I could do a call later today (5ish) or near close of play tomorrow (6ish).

If either of those slots are any good I will accept an invite for a call – say 30 minutes on Skype.

For you information we have recently tried to connect Cost and Programme Measurement activities directly. I note cost is not noted in any of this. Also Roy Hickman copied in may also be able to respond as he is involved in a team that built a very specific 4D tool.

Thanks

[redacted]

Butkovic, Bogdan
Mon 12/11/2018 13:48
To: [redacted]

Thank you for the prompt reply. Five (5pm) today is as good as 6pm tomorrow so it is up to you. I will be on Skype at that time. I need a transcript for the University so just a live text chat via Skype is OK and it does not take more than 30minutes. If your colleague wants to validate my framework it would be good too.

Kind Regards,
Bogdan Butkovic

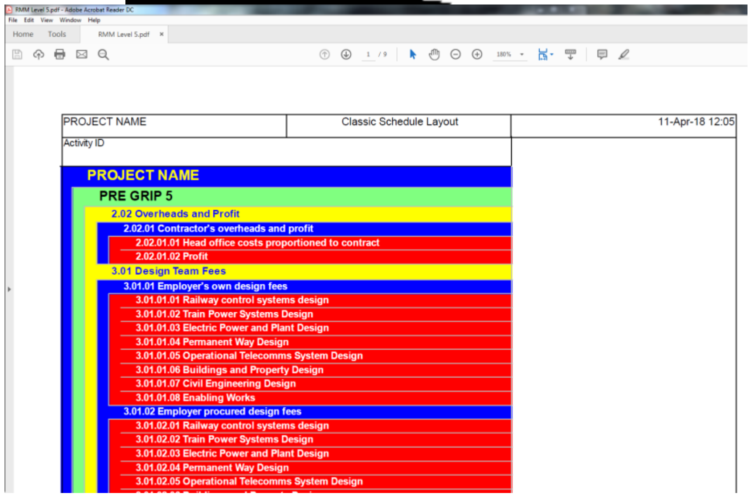
[redacted]
Mon 12/11/2018 15:02
To: Butkovic, Bogdan

RMM Level 5.pdf
71 KB

Download Save to OneDrive - University of Wolverhampton

For information a attempt at a breakdown structure to suit 4 & 5D planning.

Thanks
[redacted]



PROJECT NAME	Classic Schedule Layout	11-Apr-18 12:05
Activity ID		

PROJECT NAME
PRE GRIP 5
2.02 Overheads and Profit
2.02.01 Contractor's overheads and profit
2.02.01.01 Head office costs proportioned to contract
2.02.01.02 Profit
3.01 Design Team Fees
3.01.01 Employer's own design fees
3.01.01.01 Railway control systems design
3.01.01.02 Train Power Systems Design
3.01.01.03 Electric Power and Plant Design
3.01.01.04 Permanent Way Design
3.01.01.05 Operational Telecomms System Design
3.01.01.06 Buildings and Property Design
3.01.01.07 Civil Engineering Design
3.01.01.08 Enabling Works
3.01.02 Employer procured design fees
3.01.02.01 Railway control systems design
3.01.02.02 Train Power Systems Design
3.01.02.03 Electric Power and Plant Design
3.01.02.04 Permanent Way Design
3.01.02.05 Operational Telecomms System Design

[redacted]

Mon 12/11/2018 15:02

Let's try 5pm today.

Thanks

[redacted]

From: [redacted]
Sent: 12 November 2018 17:11:10
To: Butkovic, Bogdan
Subject: Re: Draft frameworks with short descriptions

I can't see it - I can send you a Webex link

[redacted]

On 12 Nov 2018, at 17:03, Butkovic, Bogdan <B.Butkovic@wlv.ac.uk> wrote:

I am on Skype and sent you invite. Can you see my invitation?

Regards,
Bogdan

BB Butkovic, Bogdan
Mon 12/11/2018 17:14

Sorry I cannot do it. I need a transcript. I need a live text chat. Call not good option. Can we do the LinkedIn chat?

Regards,

Bogdan

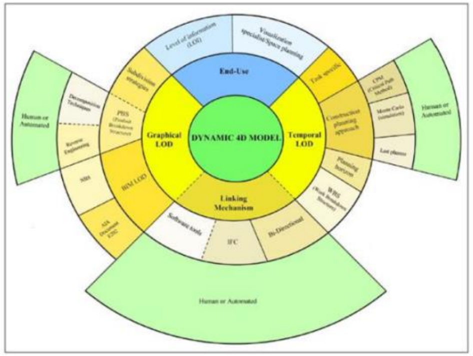
BB Butkovic, Bogdan
Mon 12/11/2018 17:53
To: [redacted] Butkovic, Bogdan

Butkovic, Bogdan [5:11 PM]:
Test
[redacted] **[5:15 PM]:**
Okay - on now
Butkovic, Bogdan [5:16 PM]:
Hi again, how are you?
[redacted] **[5:16 PM]:**
I am fine, apologies I was late
Butkovic, Bogdan [5:17 PM]:
Thank you for attachment you sent. It is interesting to see how the schedule layout goes in depth for the project.
[redacted] **[5:18 PM]:**
This is not a fully detailed draft - there are more levels, but it is a first run against the Rail Method of Measurement with a view to directly linking Programme items and cost items
Butkovic, Bogdan [5:18 PM]:
Can we start?
[redacted] **[5:18 PM]:**
Please proceed
Butkovic, Bogdan [5:18 PM]:
I want to thank you for your time and for the willingness to assist me. I appreciate that. As I need to respect the ethical rules I am not allowed to write your name on my thesis but only your job title. Could you tell me now what your job title is?
[redacted] **[5:19 PM]:**
Programme Manager for BIM
Butkovic, Bogdan [5:19 PM]:
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.
[redacted] **[5:21 PM]:**
So the first principle is this diagram you are validating
Can I send a clip with this ?
Butkovic, Bogdan [5:21 PM]:
Yes
[redacted] **[5:21 PM]:**
Just opening a white board

[redacted]
Mon 12/11/2018 17:29
To: Butkovic, Bogdan

Okay need to send this by email –

Question you are asking is – is this framework correct

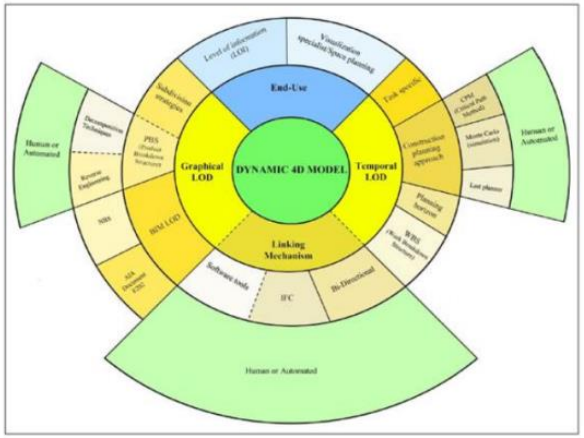


Mon 12/11/2018 17:37
To: Butkovic, Bogdan

Okay need to send this by email –

Question you are asking is – is this framework correct

1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.



- So first I would start from the core – I like the simplicity – you need to be careful of placing LOD and LOI at input and output ends – maybe a circle is not ideal ?
  - the needs of my company are now focussed on combined 4D and 5D and probably Who Life 5D with Carbon, especially for early stages
- The second circle from the core looks useful – although IFC is insufficient for geometry exchange in rail it does need a common format if possible
- Sub-division which we may call staging strategies are important – are these based on standards and rules, and the rest processes and decision trees ?
- Not entirely clear on the automated human gaps around the circle -

[redacted]

[redacted] [5:30 PM]:
Sned an email - it is hard to work this question on text because I am describing a visual framework - first comment sent

Butkovic, Bogdan [5:32 PM]:
And what do you think about the 4D LOD specification framework the one that comes after the survey?

Butkovic, Bogdan [5:35 PM]:
I saw the email and the conceptual framework was done after the literature review so now I need to work on something solid to be possible to implement in the industry. My work is concentrate on 4D improvement.

[redacted] [5:36 PM]:
So in detail
1. Do you think that the framework as presented accurately addresses the needs of your company? If your answer is yes please give some details.

- So first I would start from the core – I like the simplicity – you need to be careful of placing LOD and LOI at input and output ends – maybe a circle is not ideal ?
  - the needs of my company are now focussed on combined 4D and 5D and probably Who Life 5D with Carbon, especially for early stages
- The second circle from the core looks useful – although IFC is insufficient for geometry exchange in rail it does need a common format if possible
- Sub-division which we may call staging strategies are important – are these based on standards and rules, and the rest processes and decision trees ?

That's whole life
To focus on 4D I think the Input and Output approach is important and maybe a maturity stage of the project will affect this ?

Butkovic, Bogdan [5:38 PM]:
Yes.
I think that too.

[redacted] [5:39 PM]:
So it essence it looks a useful framework , as the breakdown structures are critical and the process flow is critical I think it is difficult to say it addresses everything - sequence and impact
But it looks like it covers most of the issues
Purpose is very important - the end use connections look light - stakeholders, safety , problem solving / identfication are all drivers for 4D - there are lots of inputs shown for sure

Butkovic, Bogdan [5:41 PM]:
Thank you and let me you ask the next question
2. If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?

[redacted] [5:44 PM]:
Well that's a dificult question because it is a framework not a specification - if you are saying all this will be set as madatory and international or national standards will set the effort / granualarity , then it coudl be quite involved.
Most projects do this on a case by case benefit basis. There is an opportunity with digital libraries and rapid engineering designs to build in assembly seuqences and then tweak timelines I guess, but if we were to take all designs and inisit on all of this capability available at any stage (feasability, optioneering and construction) that could be an enormous effort
Is that what you mean ?

Butkovic, Bogdan [5:48 PM]:
Yes
I think you have me the answer.
3. Does the framework include all the necessary components?

[redacted] [5:49 PM]:
Just to be clear we are looking at the circular diagram as the framework and the later diagram as the process ?

Butkovic, Bogdan [5:49 PM]:
Yes

[redacted] [5:50 PM]:
So the process diagram covers the end use of 4D , they only thing I would say is the iteration and applicability of componments may grow or shrink depending on stage of maturity and end user benefit
So if you laid this framework against say the digital plan of work you may see the framework lighting up or getting switched off in places
I still feel a little uncomfortable with Level of Graphical Detail and Level of Temporal detail. I think level of Definition (Graphical and Information) would be needed to ensure the end user benefits are met.
We are currently running 4D models to show what money is invested in what areas of the project and when - you could see that to revenue generation modelling also, or people flows, or vehicle flows, which temporal and graphical only information

Butkovic, Bogdan [5:54 PM]:
Ok. It is just the terminology as temporal detail is the information

[redacted] [5:55 PM]:
Okay - so not just the schedule but the activuty detail and content

Butkovic, Bogdan [5:55 PM]:
Yes. But there are so many potentials for 4D to be used.

[redacted] [5:55 PM]:
Apologies I am finding it hard to write and spell check with this small writing and my failure to get my reading glasses :-)
How are we doing on time ? I need to leave shortly, apologies

Butkovic, Bogdan [5:56 PM]:
I concentrate on answers not spellings.
I still have few more questions.
4. Where do you think the level of detail in the 4D simulation should be specified?

[redacted] [5:57 PM]:
Okay

Butkovic, Bogdan [5:58 PM]:
Let's speed. Just try 10min.

[redacted] [5:58 PM]:
In an Employers Information Requirements for a BIM project - how it is used and how it acheives benefits in a BEP

Butkovic, Bogdan [5:58 PM]:
5. Do you consider the schedule a level of detail when thinking about a 4D model?

[redacted] [5:58 PM]:
Yes - absolutely
Logistics is also hard to show - maybe from the earlier question - pathways is a missing componenet of the framework - logistical pathways / options

Butkovic, Bogdan [6:00 PM]:
6. How relevant do you think this approach would be to a typical construction project?

[redacted] [6:00 PM]:
Very relevent assuming the project had a reasonable complexity

Butkovic, Bogdan [6:00 PM]:
7. What do you think, would this framework only be valid on certain construction projects but not others?

[redacted] [6:01 PM]:
So the simple ask is are their projects that don;t need 4D modelling ?

Butkovic, Bogdan [6:01 PM]:
Yes

[redacted] [6:02 PM]:
I guess very simple renewals works could be understood , or minor works, with a desciption and a set of drawings showing sequence (an assmebly drawing which is not really a dynmaic 4D model

Butkovic, Bogdan [6:02 PM]:
8. How might you use that framework on a construction project where you need 4D?

[redacted] [6:04 PM]:
So in a BEP I would expect a supplier to provide a process map for managing inputs and outputs for 4D, in specifying 4D in EIRs you could look at sources of information and confirm responsibilities and roles in 4D modelling

Butkovic, Bogdan [6:04 PM]:
9. How might you improve the framework?

[redacted] [6:05 PM]:
I think showing it as an input - process - output model - SIPOC analysis and showing the level of maturity in projects against it - and defining if the client or supplier is responsible for the input source. Adding logistic pathways and cost level of information to the graphical may help clarify the inputs better ?

Butkovic, Bogdan [6:06 PM]:
Yes
10. What do you think is missing from my framework that needs to be included?
This is the last question.

[redacted] [6:06 PM]:
But I think it is a very useful addition to a subject which lacks theoritical mapping
Last question I think I answered partly in what could be improved - A RACI, A level of maturity, a broader list of End User Inputs / outcomes - somewhere to show the benefits link and drivers.
On the automation and human input element - not quite sure how that lands or what it means against the parts that have none - maybe clarify this is static / rules or standards inputs ?

Butkovic, Bogdan [6:09 PM]:
That would be all I am sorry for keeping you this long. Thank you so much for your time. I am so grateful for all your answers and help.

[redacted] [6:10 PM]:
You are welcome - good look with the remainder of the studies !! Kind regrads
Kind regards
[redacted]

Butkovic, Bogdan [6:10 PM]:
It is a standard rule.
All from the literature I researched.
Thank you, [redacted].

Appendix H: Ethical Approval and Survey Participants

RE: Ethical Approval - Bogdan Butkovic

[redacted]

Tue 05/12/2017 16:28

To: Butkovic, Bogdan <B.Butkovic@wlv.ac.uk>;

Hi Bogdan,
Please take this email as official notification that your revised ethics form has now been approved as of the date of this email.

Kind regards,
[redacted]
Research Administrator
Faculty of Science & Engineering [redacted]
University of Wolverhampton, City Campus (Wulfruna), Wulfruna Street, Wolverhampton, WV1 1LY
Tel: [redacted]
Email: [redacted] or for research application queries: [redacted]

From: Butkovic, Bogdan
Sent: 03 December 2017 19:08
To: [redacted]
Subject: Re: Ethical Approval - Bogdan Butkovic

Dear [redacted],

I hope you had a good weekend. I have corrected the question No. 19 as assumed only question to be corrected. I amended the answer which obviously I early omitted while others are left the same and not changed. I hope that it is in order by now. Please, let me know if anything more is necessary to be done.

Regards,

Bogdan Butkovic

From: [redacted]>
Sent: 01 December 2017 19:41

Ethical Approval Form (Faculty of Science and Engineering)

Survey input field	Respondent's answer
Name:	Bogdan Butkovic

1. Please enter your surname and first name below. (SURNAME, FIRST NAME)

Butkovic, Bogdan

2. Please enter your University email address (e.g. M.Name@wlv.ac.uk)

b.butkovic@wlv.ac.uk

3. Please enter the name of your Director of Studies, Principal Investigator or, for Principal Investigators, your line manager.

Dr. David Heesom

4. Please enter date by which a decision is required below. (Note that decisions can take up to 4 working weeks from date of submission)

4th December 2017

5. Which subject area is your research / project located?

1. **Architecture and Built Environment**
2. Biology, Chemistry and Forensic Science
3. Engineering
4. Life Sciences
5. Mathematics and Computer Science
6. other

6. Please select your School

1. **School of Architecture and Built Environment**
2. School of Biomedical Science and Physiology
3. School of Biology, Chemistry and Forensic Science
4. School of Engineering
5. School of Mathematics and Computer Science
6. School of Pharmacy
7. Other (please specify below)

7. Does your research fit into any of the following security-sensitive categories? (For definition of security sensitive categories see RPU webpages (www.wlv.ac.uk/rpu) follow links to Ethical Guidance).

1. commissioned by the military
2. commissioned under an EU security call
3. involve the acquisition of security clearances
4. concerns terrorist or extreme groups
5. **not applicable**

8. Does your research involve the storage on a computer of any records, statements or other documents that can be interpreted as promoting or endorsing terrorist acts?

1. YES
2. **NO**

9. Might your research involve the electronic transmission (eg as an email attachment) of any records or statements that can be interpreted as promoting or endorsing terrorist acts?

1. YES
2. **NO**

10. Do you agree to store electronically on a secure University file store any records or statements that can be interpreted as promoting or endorsing terrorist acts. Do you also agree to scan and upload any paper documents with the same sort of content. Access to this file store will be protected by a password unique to you. Please confirm you understand and agree to these conditions?
1. YES I understand and agree to the conditions 2. **NO (please explain below)** 3. I do not understand the conditions
I am not supporting neither promoting any statement related to terrorist acts and as such I would never agree to be involved in any similar activity as to store, scan or upload electronically any such the documents.

11. You agree NOT to transmit electronically to any third party documents in the University secure document store?
1. **YES I agree** 2. NO I don't agree

12. Will your research involve visits to websites that might be associated with extreme, or terrorist, organisations? (for definition of extreme or terrorist organisations see RPU webpages (www.wlv.ac.uk/rpu) and follow links to Ethical Guidance.
1. YES (Please outline which websites and why you consider this necessary) 2. **NO**

13. You are advised that visits to websites that might be associated with extreme or terrorist organisations may be subject to surveillance by the police. Accessing those sites from university IP addresses might lead to police enquiries. Do you understand this risk?
1. **YES I understand** 2. NO I don't understand

14. What is the title of your project?
Impact of 4D LOD (Level of Detail) on communication in construction projects

15. Briefly outline your project, stating the rationale, aims, research question / hypothesis, and expected outcomes. Max 300 words.
Based on the foregoing, the aim of this project is the development of a Level of Detail (LOD) framework for a 4D BIM to enhance communication at various stages of the construction process. The study objectives are: 1. A critical review of prevailing literature in the field of BIM and 4D modelling. 2. Investigating the value of current 4D modelling tools used for schedule visualization in construction engineering. 3. Analysing the activity sequencing and findings incorporated in the research and the effect of communication between the design and construction team in the real-life construction project (UoW). 4. Developing the framework. 5. Validating the framework.

16. How will your research be conducted? Describe the methods so that it can be easily understood by the ethics committee. Please ensure you clearly explain any acronyms and subject specific terminology. Max 300 words
The main objective in this research to identify or confirm the potential lack of awareness and potential needs for improvement toward the dynamic 4D modelling. The questionnaire seeks to obtain information from the specific AEC related disciplines (architects, contractors and project managers) on their current use and opinion of 4D modelling. The survey contains general questions in addition to a range of qualitative and quantitative questions as scope of work with a dynamic 4D model use, identification of strengths, weaknesses and potential improvements. Observing, questioning and collecting data would also provide further development of the theoretical framework and would justify the needs for developing of novel software platform.

The survey was divided into four sections of information (personal, company, Dynamic 4D model and example tasks) in order to generate data concerning various companies which currently use BIM and their involvement in the construction industry. It is anticipated that these results will be compared with the results from the literature review findings.

17. Is ethical approval required by an external agency? (e.g. NHS, company, other university, etc)

1. **NO**
2. YES - but ethical approval has not yet been obtained
3. YES - see contact details below of person who can verify that ethical approval has been obtained)

18. What in your view are the ethical considerations involved in this project? (e.g. confidentiality, consent, risk, physical or psychological harm, etc.) Please explain in full sentences. Do not simply list the issues. (Maximum 100) words)

My research was based on the literature review and the designed framework is the original idea therefore the confidentiality and consent would be the main ethical considerations involved in this project. Without my permission no individual or company should use the work achieved in this project.

19. Have participants been/will participants be, fully informed of the risks and benefits of participating and of their right to refuse participation or withdraw from the research at any time?

1. **YES (Outline your procedures for informing participants in the space below.**
2. NO (Use the space below to explain why)
3. Not applicable - There are no participants in this study

Participants will be fully informed through SurveyMonkey about the questionnaire procedures, where in the introduction part of the survey it will be explicitly explained that the participant can refuse or withdraw at any time.

20. Are participants in your study going to be recruited from a potentially vulnerable group? (See RPU website (www.wlv.ac.uk/rpu) and follow link to Ethical Guidance pages for definition of vulnerable groups)

1. YES (Describe below which groups and what measures you will take to respect their rights and safeguard them)
2. **NO**

21. How will you ensure that the identity of your participants is protected (See RPU website (www.wlv.ac.uk/rpu) and follow link to Ethical Guidance pages for guidance on anonymity)

The research project is not a risk or not providing the hazards for the participants. The goals of the collecting data are described in the questionnaire. After data analyses when the report will be written the interviewed bodies will not be identified by names and addresses.

22. How will you ensure that data remains confidential ((See RPU website (www.wlv.ac.uk/rpu) and follow link to Ethical Guidance pages for definition of confidentiality)

When data is collected and report is written the respondent's identify will be protected. The identifying information will be changed by the study codes.

23. How will you store your data during and after the project? (See RPU website (www.wlv.ac.uk/rpu) and follow link to Ethical Guidance pages for definition of and guidance on data protection and storage).

The data will be stored on the personal computer files and password protected. This data will be accessible only by myself.

Survey Participants through SurveyMonkey

1 to 306 pages

Dropbox download link:

https://www.dropbox.com/s/vzz8unwknxn5aho/Responses.pdf?dl=0

Appendix I: Publications

Butkovic, B. and Heesom, D. (2017) Towards A Framework For Multi-LOD 4D BIM Simulations. *International Research Conference 2017*. University of Salford, 11-12 September, pp. 578-586

Butkovic, B., Heesom, D. and Oloke, D. (2018) The Framework Validation for Dynamic 4D BIM Simulations. *1st International Conference on Construction Future 2018 (ICCF2018)*. University of Wolverhampton, 19-20 December

Butkovic, B., Heesom, D. and Oloke, D. (2019) The need for multi-LOD 4D simulations in construction projects, ITcon Vol. 24, pp. 256-272, https://www.itcon.org/paper/2019/14

TOWARDS A FRAMEWORK FOR MULTI-LOD 4D BIM SIMULATIONS

Bogdan Butkovic[1] and David Heesom[1]

[1]*Architecture and Built Environment, University of Wolverhampton, Wolverhampton, WV1 1LY, UK*

Email: B.Butkovic@wlv.ac.uk

Abstract: In any construction project, the absence of sufficient information required for decision-making at the planning stage is one of the biggest problems. With emerging technology, the very act of designing change, from 2D drawings to 3D digital models, opens up the opportunity to assemble the models in the same way as a building is constructed. The use of Building Information Modelling (BIM) is now a critical aspect of the construction process and using this process, the development of a 3D model starts early in the development cycle. The Level of Graphical Detail (LOD) of the 3D model is affected by the time planned to build it and the size of the model and these important items need to be communicated. The level of detail of the information included in BIM also has an impact on the anticipated 4D usage executed by practitioners. This is a difficult topic because 4D simulations integrate both 3D components and construction activities schedules. Therefore, the BIM level of development incorporates geometry and non-graphical information. For that reason, a '4D LOD' requirement must manage both the graphical level of detail and the temporal level of detail. Whilst a wide range of research has been undertaken over the last 15 years in the field of 4D modelling, little has been presented in terms of developing an approach to understanding the level of detail required for 4D simulations. Based on the foregoing and an in depth review of the current status of 4D BIM, in particular issues surrounding the level of detail of 4D simulations and BIM in general, a framework is proposed to support the development of more dynamic 4D modelling. The anticipated framework attempts to focus on key issues identified in the literature. It seeks to address problems acknowledged within current construction planning practice together with the drawbacks and future capabilities of 4D methodologies, through the application of new technological solutions, directed towards a strong and innovative approach to construction plan creation.

Key words: 4D model, project planning, collaborative work, level of detail

1. INTRODUCTION

In a construction project, the absence of sufficient information required for the decision-making at the planning stage is one of the biggest problems (Winch *et al*., 1998). At the commencement period of a construction project, the result of the construction project is a little more than an idea and ambiguity is very high. With emerging technology, the very act of designing is changing from 2D drawings to 3D digital models and this opens up the opportunity to assemble the models in the same way as a building is constructed. These 3D building models could be spontaneously manipulated and collaboratively used in different phases of building construction (Song *et al*., 2012).

The use of Building Information Modelling (BIM) is now a critical aspect of the construction process and using this process the development of a 3D model starts early in the development cycle. The Level of Graphical Detail (LOD) of the 3D model is affected by the time planned to build it and the size of the model and these important items need to be communicated. The level of development describes the accuracy of the 3D components and the quantity of information contained by each component. Level of Detail essentially defines model evolution (Bedrick, 2013). LOD in BIM is defined based on elements and the progression of the elements all through the project from the lowest level approximation (conception design) to the highest level of the representation (as-built). The American Institution of Architects (AIA) has been developing principles to assist communication during the construction project. AIA E202 is a document providing guiding principles about the models indicating the relationship of the level of development with the proposed use of the model at every stage of the project (Kensek, 2014).

The level of detail included in BIM has to fit to the anticipated 4D usage executed by practitioners. This is a difficult topic because 4D simulations integrate both 3D components and construction activities' schedules. Trani *et al.*, (2015) noted that the Level of Graphical Detail of a 3D model changes from one stage of the construction process to another. Winch (2010) highlights that the utilization of 4D BIM provides the opportunity to link together the PBS and WBS at key stages, however these stages of design and construction evolve and subsequently so does the 3D model.

These construction accomplishments in projects are usually produced by different stakeholders in unsynchronized processes. Therefore, the BIM level of development incorporates geometry and non-graphical information. For that reason, a 4D LOD requirement must manage both the graphical level of details and the temporal level of information. Additionally, levels of detail must correspond to the industry needs' and the estimated usage of the model at different phases of the construction project (Boton *et al*., 2015a). This is a specific area of research that has attracted a limited amount of research in comparison to other aspects of BIM implementation.

2. LITERATURE REVIEW

Whilst a wide range of research has been undertaken over the last 15 years in the field of 4D modelling, little has been presented in terms of developing an approach to understand the specific level of detail required for 4D simulations. Aouad *et al*. (2012) did postulate that more dynamic 4D simulations were required in order to achieve more reliable outcomes, when used in the planning process. Boton *et al*. (2015) also noted that levels of detail of the graphical models used during any 4D simulation must correspond to the industry needs' and the usage of the simulation at different phases of the construction project. Building on these issues, it has also been acknowledged that any specification of 4D LOD should manage graphical level of detail and the temporal level of information, in order to deliver realistic and more reliable 4D simulations (Tolmer *et al*., 2015a). However, little has been undertaken to formalize these issues to provide higher quality, more useful 4D simulations. Much of the work undertaken around the issue of graphical level of detail is primarily focused on the graphical representation of objects within the Building Information Model, and indeed the UK NBS standards and USA AIA standards focused on this issue are key documents in the BIM Process.

Four-dimensional (4D) BIM has been recognized as an approach which improves construction planning techniques. The combination of 3D CAD with the schedule data has been quoted as the indicator of design and planning errors in many construction projects. Trebbe *et al*., (2015) highlight how 4D BIM can be used to understand complex interconnections between different stages of construction work in any project. 4D model elements connected in 3D CAD models, allow project stakeholders to view all the accomplishments from design, procurement and construction schedules. All the planned construction of a building over time is shown on the screen and provides a 3D CAD model review for any day, week, or month of the project. In addition, it is believed that the use of these tools helps project participants reduce risk, attracting quality team players, which is very important as the industry deals with the problem of the tight labour market (Zhou *et al*., 2009a).

A 4D BIM has shown good potential as a starting point for planning progress and carrying out model based progress monitoring. However, the construction practices are still costly, with many errors and irregular completion. Researching the causes for these errors is able to improve future models. The level of detail in the BIM model is not appropriate enough for following the progress on a component-by-component basis (Han and Golparvar-Fard, 2015). Document coordination and installation coordination are crucial for providing better structure and quality and causing fewer issues during construction and during operation. (Hardin and McCool, 2015).

The solution for comprehending collaborative 4D planning is in the collaborative planning workflow. Starting with a shared 3D model that is manageable by all designers, this allows them to foster a collaborative scheduling session and continue work with multilevel communication. This interaction among planners allows them to perform their planning more effectively. Using a 3D model as a start, everyone involved in the planning process is able to evaluate the design, discuss planning approaches with each other, and propose solutions. The fact is that 3D and 4D process synchronization has an immense impact on the project's outcome (Zhou *et al*., 2009b).

Building of a structure always goes gradually and these 3D models are not typically designed for 4D modelling, the model designers need to have 3D model layering systems that support the 4D activities (Aouad *et al*., 2012a). 3D models have to be structured into work components to match the level of detail in the schedule. Geometric information has to be employed into different layers and 'CAD' components reorganized onto different sets. Absence of appropriate level of detail in 4D models was pointed out by Heesom and Mahdjoubi in 2003 when they were evaluating the construction process by using 4D models. They concluded that developing more dynamic 4D simulations would provide more realistic and more accurate results. However, for more than a decade this issue has not been addressed (Heesom, 2006a).

4D modelling techniques can simulate the construction process and identify potential conflicts in construction plans. The technique can be generated in a computer dynamic 3D construction process with a time progressing component, which allows 4D modelling to disclose hidden conflicts and enable an update and amendment of construction plans (Zhou *et al*., 2014).

2.1 Technology for 4D and current applications

4D modelling is supported with many software applications (Table 1), whether they are part of a suite or stand-alone third-party applications. 3D elements are connected with time by either specifying detailed points within the modelling application, or by introducing a project schedule into the application. When forming a 4D model, the 3D model is brought in together with the project schedule and the link is then made in the application.

Table 1: 4D Tool / Applications

Company / Tool	Description	Linkage	Multiple LOD simulation
Bentley / Project Wise Navigator	Provides Project and analyse wise schedule simulation. Import 2D and 3D design files difference sources	Importing and connecting schedule information from Microsoft Project, Excel or Primavera. Reviewing interfaces (clashes) and viewing and analysing schedule simulations	No
Autodesk / Navisworks Suite JetStream TimeLiner	Supports various numbers of BIM formats and has overall very good visualization capabilities Permits the importation of schedules from a variety of sources	Supports manual and automatic linking to imported schedule data from variety of schedule applications Allows the user to join the items in the model with the tasks and simulate the schedule	Use of the images and animations created bring simulation up to date automatically if the model is changed.
Innovaya / Visual Simulation	Combines BIM objects with planning activities to complete a 4D construction. Generates simulation of construction process	Increases the project communication, synchronization and logistic scheduling. Links 3D design data in DWG with Microsoft Project or Primavera	No
Syncro Ltd / Syncro 4D	New 4D tool with improved scheduling and project management	Covers risk and resource analyses features and include built in tools to visualize risk, buffering and recourse usage in addition to 4D visualization	No
VicoSoftware / Virtual Construction	5D construction planning system which covers Constructor, Estimating, Control and 5D Presenter	Schedule data can be imported from Microsoft Project or Primavera and any changes in scheduling system are automatically reflected in the 4D visualization	No

If the 3D model and the schedule are established appropriately the connecting of the two elements together to form the 4D model should be a direct process. Lately some software applications have been technologically advanced to provide automated connecting, based on the exclusive indicators defined in both 3D modelling and planning software. During the construction development, the 3D design model and construction schedule have to be considered.

The current market offers several 4D CAD software applications. Bentley Navigator provides Project Wise Schedule Simulation for additional awareness of critical project schedule information, by importing and connecting to schedule information, accomplished in Microsoft Project, Excel or Primavera.

4D CAD Modelling software in Innovaya Visual Simulation combines BIM objects with planning activities to complete 4D construction preparation and constructability review. This tool successfully increases the project communication, synchronization and construction logistics scheduling. Visual 4D Simulation incorporates a very strong 3D appliance and in particular an approachable intersection. Therefore it benefits, builds and improves task systems which provide project time savings (Aouad *et al*., 2012b).

Even though 4D modelling has been recognized as technology with clear advantages during the design and construction process, a number of weaknesses have been noticed when applying technology during the construction project. Limitations of 4D modelling are (Aouad *et al*., 2012c):

- The need for two or more software applications in order to integrate design and planning information.
- The absence of construction plan information as the construction activities could not all be visually presented.
- No clear evaluation and duration of activities in the project.
- Persistent need for the Gantt chart to present activities' relationships
- The project team still have to modify or optimize the schedule manually for a 4D model in order to completely recognize its benefits.
- Lack of more dynamic 4D simulation in order to achieve more reliable outcomes

2.2 LOD in 4D modelling

The level of detail and in particular the granularity of individual geometric objects included in BIM has to fit to the anticipated 4D usage executed by practitioners. This is a difficult topic because 4D simulations integrate both 3D components and construction activities' schedules. For that reason, a 4D LOD requirement must manage both the graphical level of details and the temporal level of information. Additionally, levels of detail must correspond to the industry needs' compatibility with the estimated usage of the model at different phases of the construction project (Boton *et al*., 2015b). There are two critical factors that exist when thinking towards the end usage of a 4D model. Firstly, the planning horizon used and subsequently the time period between state changes in the simulation i.e. 1 day, 1 week etc. Secondly having geometry at a level of granularity that can be linked to tasks produced at the relevant planning horizon to present an accurate reflection of the construction sequence. Thus far, limited research has been undertaken on the critical issue of 4D LOD issues, although the importance of the level of detail and its impact on BIM projects has been indicated repeatedly in available literature. As BIM level of development includes geometry and non-graphical information, 4D LOD has to manage both graphical levels of detail and temporal level of information. Moreover, the levels of detail need to agree to industry requirements compatible with the expected usage of the model at different phases of the construction project (Heesom, 2006b). To date there is no standards or benchmarks produced in this field and so considerable research is required in order to fill this void in knowledge.

Han and Golparvar-Fard (2015) suggest that the lack of detail in the 3D BIM used for the pre-construction purpose in projects is not sufficient enough for tracking the progress on individual element bases. LOD300-400 is similar to less detailed models than traditional construction documents.

Boton *et al*. (2015) presented a case study of the development of 4D models at various stages of the design and construction process. However, the development of the Level of Detail within this project was predominantly focused on the graphical detail of the design model. Models were generated in accordance with the AIA LOD 100-600 series using a range of software tools and then 4D simulations were created. The work did highlight the changes required for the resolution of the plan at each stage and this was appropriate for the detail of the graphical model, also noting that LOD required for the construction phase is higher than the LOD needed in the pre-construction phase (Kriphal and Grilo, 2012). However, it did not resolve the critical issue of decomposition of construction product elements for the generation of more dynamic 4D models and whether this is also required to change to meet the needs of project planning through the various phases of the lifecycle of the design and construction. The study did conclude that a single graphical LOD is not adequate during the construction phase and that different levels of development were needed for visualization and coordination, depending on the 4D model purpose and the specific construction problems that occurred during construction and modelling processes. This view is supported by McGeorge and Zou (2013) who note the understanding of complex models could be aided by the technique of model decomposition that subdivides models into smaller significant sub-models in order of their conception.

It is apparent that in 4D models, LOD specification should manage graphical levels of detail and the temporal level of information in order to deliver realistic and more reliable 4D simulations (Tolmer *et al*., 2015b).

3. CONCEPTUAL FRAMEWORK FOR MULTI-LOD 4D BIM

Based on the foregoing review of the current status of 4D BIM and in particular issues surrounding the level of detail of 4D simulations, a framework is proposed to support the development of more dynamic 4D simulations.

The anticipated framework attempts to focus on key issues identified in the literature. This conceptual framework is set to address problems acknowledged within current construction planning practice and the drawbacks and future capabilities of 4D methodologies through the application of new technological solutions, directed towards a strong and innovative approach to construction plan creation.

It is anticipated that the implementation of this framework through a novel software platform would improve current planning practices by allowing appropriate, visual planning through in-built communication within a building information model. Furthermore, more dynamic 4D modelling would promote and enable more collaborative and coordinated construction planning.

The focus of the framework is the Dynamic 4D model (D4DM) such that the planner can produce and utilize more realistic and representative simulations of the construction process at various temporal and graphical resolutions. The construction planner should have the ability to decompose a single component into sub elements according to areas and related activity into sub activities. This technique proposed by Akbas and Fischer (2002) is postulated in the framework. These areas can be created at different levels of detail to contribute to a more comprehensive view of the schedule (Fischer *et al*., 2000). Many parts, including the shape of the construction zone, import the efficiency level used during the progress of the dynamic phase of the geometry axes (Akbas, *et al*., 2001).

A 4D simulation contains a link between both the 3D model's objects (graphical LOD) on one side and the construction activities' time schedule (temporal LOD) on the other. They are both usually part of asynchronous process. It is important that a 4D model's LOD specification must manage graphical LOD and temporal LOD information. The importance of LOD is to specify all information that the model needs to have included at every stage of the project duration. The work in progress in the centre allows the planer to monitor different stages of the model at different level of detail where various levels of development were defined from LOD 100 to LOD 500 produced at various construction times during different construction tasks. The proposed framework emphasizes the necessity for planning, controlling and coordinating construction phases using visualized analysis of conflicts and clashes in models even before construction works.

Levels of accuracy that are possible in the budget are usually seen through the appraisals of product breakdown structures (PBS) used for initial-stage budgetary planning and the work breakdown structure (WBS) used throughout the scheduling and implementation phases of the project (Winch, 2010). As construction project planning concentrates on time and cost management planning is a continuous task. The WBS method delivers an extended way to calculate, outline, measure and control the elements of a given work scope. This is the reason why the PBS and WBS must be included in the framework as the PBS is part of preliminary project phase financial planning and the WBS is part of the development of project execution and scheduling during the course of the project. The level of granularity of each of these has to be coordinated in order to ensure that a dynamic 4D model is fit for purpose.

The capability to decompose building products in a 3D model is fundamental in the execution of accurate multiple level of detail in a 4D simulation. The development of the geometry reflecting the development of a building product is essential to be presented and to be created in alignment with the temporal resolution of a construction task. The technique of model decomposition that subdivides models into smaller significant sub-models is a great asset for understanding the complex models.

Any novel software platform requires simple methods of human computer interaction, and this requires the need for quality user interface characteristics. Computer graphics and applications involve visual designs of images, animation and 3D virtual reality and products. In building design, the engineering characteristics are just as important as the aspects of appearance. The function depends on visual qualities and quantitative analysis.

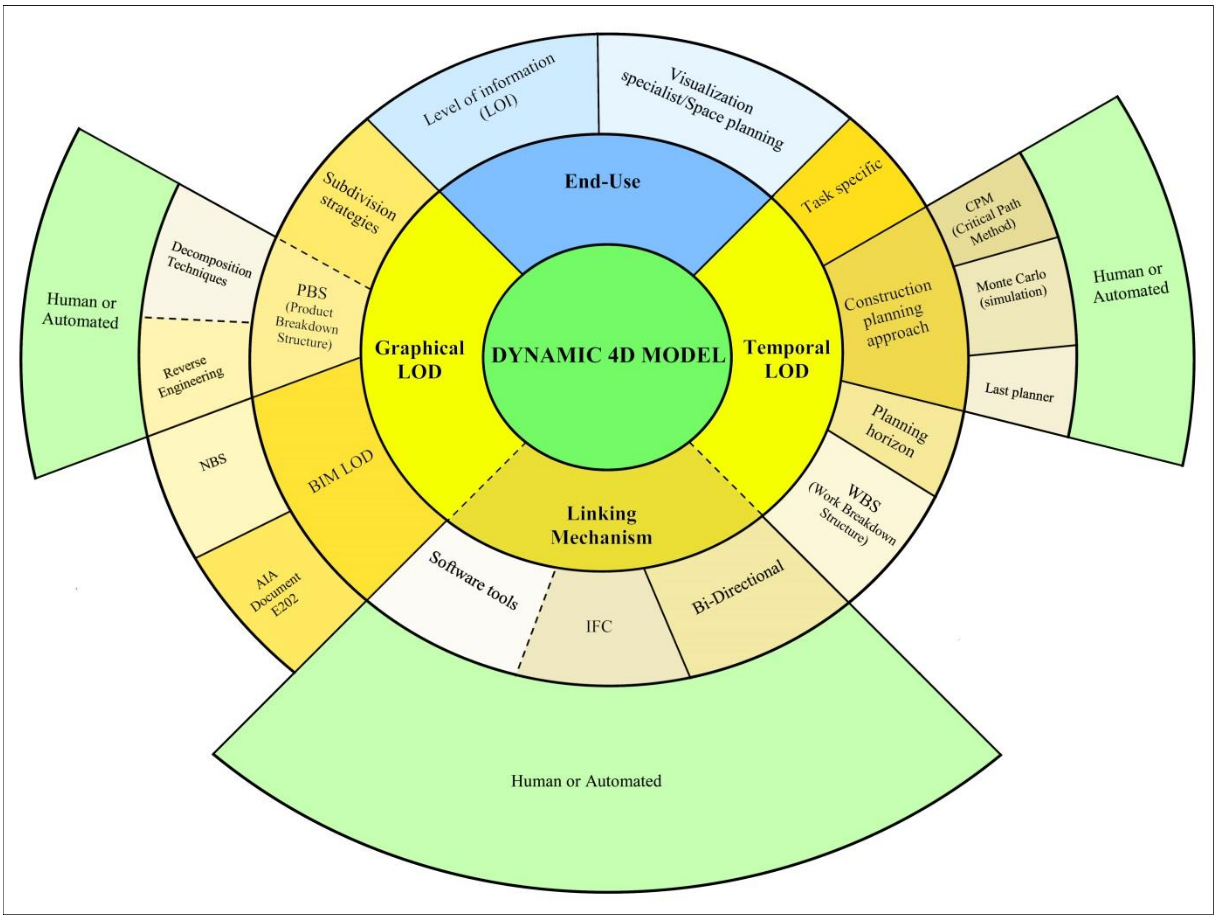


Figure 1: Conceptual framework of Dynamic 4D model (D4DM)

4. CONCLUSIONS AND FUTURE WORK

4D is evolving as a construction planning technology to address some of the challenges currently faced by the AEC industry. 4D planning has the ability to increase the visualization of the building design and construction. This 4D technology can improve the visualization but still needs time to reach maturity. Where 4D technology has been included the outcomes indicate savings and a growth in productivity. The use of 4D shows that it can save money on construction projects by recognizing difficulties seen in earlier construction projects and by avoiding re-work during the project.

This study presents a framework for creating a more dynamic 4D model by using information from Building Information Modelling. The critical parts of the conceptual framework are the graphical level of detail and various levels of temporal detail. Both graphical and temporal levels of details are influenced by numerous factors crucial for the construction project. Further work in this research study will include the development of an industry based questionnaire to further develop the conceptual framework and specific assess industry requirements for each of the key attributes.

Subsequent to this an appraisal of most appropriate software tools will be undertaken to progress the development of prototype software tool that will allow the generation of interactive dynamic 4D simulations at multiple levels of detail. Preliminary technology and software evaluation have identified Autodesk Dynamo as having the potential to develop a prototype due to having the ability to obtain geometric control within in a BIM environment and externally to the underlying project planning database that is not possible when using a conventional modelling interface. Furthermore, Autodesk Navisworks is being investigated as a potential Commercial Off The Shelf (COTS) tool to support prototype development. Navisworks supports manual and automatic linking of geometry to schedule data from a variety of schedule applications.

5. REFERENCES

Akbas, R., and Fischer, M. (2002) *Construction Zone Generation Mechanisms and Applications*, ISARC 2002, 19th International Symposium on Automation and Robotics in Construction, Sep. 23-25, 2002, Washington DC, USA, NIST SP 989, William C. Stone, editor, pp. 293-298.

Akbas, R., Fischer, M., Kunz, J. and Schwegler, B. (2001) CIB W78 Conference, IT in Construction in Africa, Mpumalanga, South Africa, 29 May- 1 June, 2001

Aouad, G., Lee, A., Wu, S. and Onyenobi, T. (2012) *Computer Aided Design Guide for Architecture, Engineering and Construction.* New York: Spon Press

Bedrick, J. (2013) *A Level of Development Specification for BIM Processes* [blog entry]. [Accessed 16 November 2015]. Available at: <http://www.aecbytes.com/>

Boton, C., Kubicki, S. and Halin, G. (2015) The challenge of level of development in 4D/BIM simulation across AEC project lifecycle. A case study, *Procedia Engineering*, **123**, pp.59-67

Fischer, M., Guibas, L. J., Kunz, J. and Akbas, R. (2000) *Geometric Representations for Construction Planning and Scheduling*. CIFE Seed Proposal, Unpublished. CIFE, Stanford University.

Han, K.K. and Golparvar-Fard, M. (2015) Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs, *Automation in Construction*, **53**, pp.44-57

Hardin, B. and McCool, D. (2015) *BIM and Construction Management* [online]. Indianapolis: Wiley. [Accessed 10 October 2015]. Available at: <https://www.dawsonera.com/>

Heesom, D. (2006) *Interactive Generation of 'Multi-Level of Detail' 4D CAD Simulation: 6th International Conference on Construction*. Application of Virtually Reality, Orlando, Florida, August 2006

Kensek, K.M. (2014) *Building Information Modeling*. New York: Routledge

Kriphal, M. and Grilo, A. (2012) Compatibility between design and construction building information models, *ECPPM Proceedings*, pp.447-452

McGeorge, D. and Zou, P. (2013) *Construction Management: New Directions.* 3rd ed. West Sussex: Wiley

Song, S., Yang, J. and Kim, N. (2012) Development of a BIM-based structural framework optimization and simulation system for building construction, *Automation in Construction*, **63**, pp.895-912

Tolmer, C.E., Castaing, C., Morand, D. and Diab, Y. (2015) Information management for linear infrastructure projects: conceptual model integrating Level of Detail and Level of Development: *Proc. of the 32nd CIB W78 Conference*. University of Technology, Eindhoven 27-29 October. Rotterdam: International Council for Research and Innovation in Building and Construction, pp.735-743

Trani, M.L., Cassano, M., Todaro, D. and Bossi, B. (2015) BIM level of detail for construction site design. A case study, *Procedia Engineering*, **123**, pp.581-589

Trebbe, M., Hartmann, T. and Andre, A. (2015) 4D CAD models to support the coordination of construction activities between contractors, *Advanced Engineering Informatics*, **49**, pp.83-91

Winch, G.M. (2010) *Managing Construction Projects.* 2nd ed. West Sussex: Wiley

Winch, G.M., Usmani, A. and Edkins, A. (1998) Towards Total Project Quality: A Gap Analysis Approach, *Construction Management and Economics*, **16**, pp.193-207

Zhou, W., Heesom, D., Georgakis, P., Nwagboso, C. and Feng, A. (2009) An interactive approach to collaborative 4D construction planning, ITcon Vol. 14, Special Issue Technology Strategies for Collaborative Working, pp. 30-47, http://www.itcon.org/cgi-bin/works/Show?2009_05

Zhou, W., Heesom, D. and Tah, J.H.M. (2014) User-centred design for collaborative 4D modelling, *Construction Innovation*, **14**(4), pp.493-517

University of Wolverhampton
School of Architecture and Built Environment

This is to certify that

Bogdan Butkovic

attended & presented at the

International Conference on Construction Futures (ICCF)

19th – 20th December 2018

Professor Mohammed Arif
Head, School of Architecture and Built Environment
Professor of Sustainability and Construction Futures
December 2018

The Framework Validation for Dynamic 4D BIM Simulations

B Butkovic, b.butkovic@wlv.ac.uk
University of Wolverhampton, UK

D Heesom, d.heesom@wlv.ac.uk
University of Wolverhampton, UK

D Oloke, d.oloke@wlv.ac.uk
University of Wolverhampton, UK

Abstract
Construction practice is changing in terms of people, process communication and working culture. By sharing knowledge resources, BIM reduces the need for re-formation of information. This increases the possibility of better communication and speeds up the construction process, reducing the cost associated with a lack of interoperability. The solution for comprehending collaborative 4D planning is in the collaborative planning workflow. A shared 3D model that is manageable by all designers, allows them to foster a collaborative scheduling session and continue working with multilevel communication. However, the construction practices are still costly, with many errors and irregular completion. Researching the detection of the causes for these errors is in the plan model. The level of detail in the BIM model is not appropriate enough for following the progress on a component-by-component basis. The aim of this research was to develop a Level of Detail (LOD) framework for a 4D BIM to increase communication at various stages of the construction process. A mixed research method approach was developed to address the needs for the successful framework development. The research methods employed in the study are consisted of: the literature review, quantitative survey and qualitative analyses of data gathered. After the framework development, the interviews with 4D simulations of experts were conducted and their perceptions and opinions stimulated the development of the framework for specifying the LOD of a 4D simulation (LOD_{4d}). Outcomes from the main survey, the framework validation and the feedback from construction professionals were verified as encouraging. Moreover, the construction suggestions were provided from the industry specialists to further support the applicability of the approach in the future.

Keywords: Framework, Validation, 4D simulation, Level of Detail (LOD), BIM

1 Introduction

4D planning should be enhancing communication among various parties involved in the construction through adopting the visualization for business needs, reduction in rework by having automated system of minimizing conflicts and provide better budget control as well as improving safety management on site. The aim of the study is to investigate a methodology directed to the development of a concrete framework and recommended approach for the execution of new functionality software for an improved dynamic 4D model. As the level of detail stages the records the model must include according to its use at the numerous phases of a project lifecycle the multi-level of detail is the strategy to be framed in the anticipated method. The temporal LOD is the time related component which represents various stages in 3D model construction operations. The whole construction process is quite dynamic and sometimes unpredictable, and could change the operation at any time while other operations require significant time so any change could take effect in the 3D model.

It is apparent that a 4D simulation does not cover varying productivity factors used in dynamic construction processes and that causes common usage of single planning intervals for the entire project duration with no automated adjustment of the temporal LOD. Automated concept was meant to provide a more dynamic and realistic method for space planning in the construction industry.

2 Related existing standards and framework

In the construction project, the lack of information required for the decision making and maintaining the smooth running of the project is the biggest problem which was first pointed out by Winch (2010) who summarized the approach to the project management.

At the commencement period of a construction project, the result of the contraction project is a little more than an idea as at this stage the ambiguity is very high. How high the uncertainty could be depends upon a numerous aspects such as the degree to which the asset is a copy of the ones existing; the level to which consistent components and solutions can be used; and the range of the requirement for new technologies to solve the specific problems sat by the project. This might serve as starting a mission and undertaking ambiguity inbuilt in the project. As the project develops, uncertainty is decreased as more information becomes available which provides for insignificances in design to be resolved.

According to Morris, project management is about the entire process but not just about recognizing a requirement for time, cost and quality. Furthermore, he separates “the management of project” as a planned approach from “the project management” as a toolbox method for carrying the project operations. Construction projects bring together assets and human resources. There are also resources of equipment as well as components and materials supplied by firms outside the construction industry. Usually the large number of different types of operatives and equipment is required for each project. The project team comes together sharing projects objectives in order for each team member to meet its individual objective (Winch, 2010).

The progress level is where the project is executed through a flow of information which initiates and controls the movement of materials. It becomes impossible to keep all the data in the model. This would make the objects and later on the model overloaded. The connection to other interactive bases provides a broader source of information and empowers the object making it a rich source of information (Mordue *et al*., 2016).

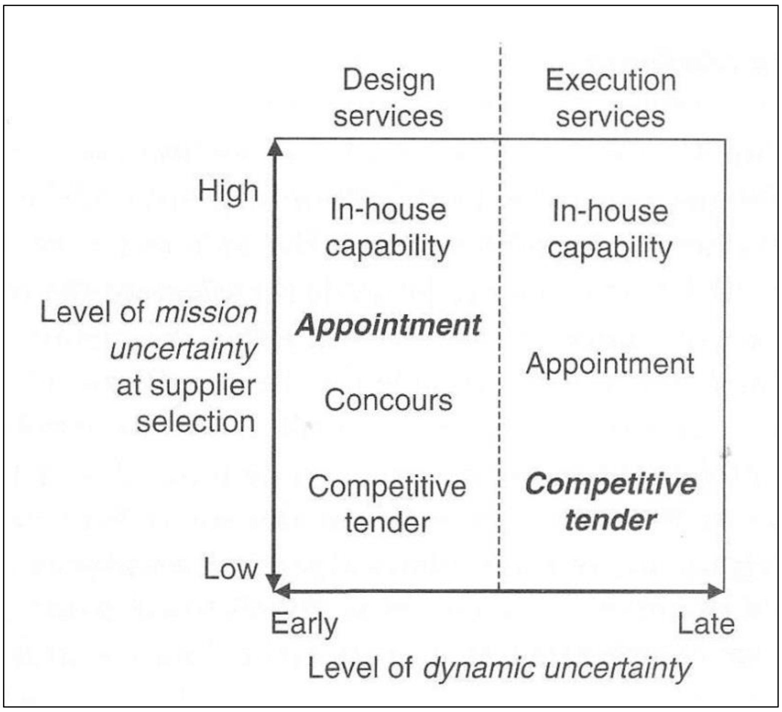


Figure 1 Supplier selection methods (methods in bold are the most common at each phase) (Source: Winch, 2010)

2.1 Conceptual framework

The evaluation carried out in in the research revealed numerous limitations and possible opportunities in established construction planning techniques and tools. Taking in consideration the recognized limitations with existing methods to 4D technologies led to the development of a new framework for more dynamic 4D modelling.

The anticpated framework attempts to focus on key issues identified in the literature review. This coneptual framework is set to address problems acknowledged with current construction planning practice and the drawbacks and future capabilities of 4D methodololies through the application of new technological solutions, in the direction to strong and innovative appraoch of construction plan creation.

It is anticpated that the application of this framework would improve current planning practices by allowing appropriate, visual planning through in-built communication within a building information model. Furthermore, more dynamic 4D model would promote and enable more collaborative and coordinated construciton planning.

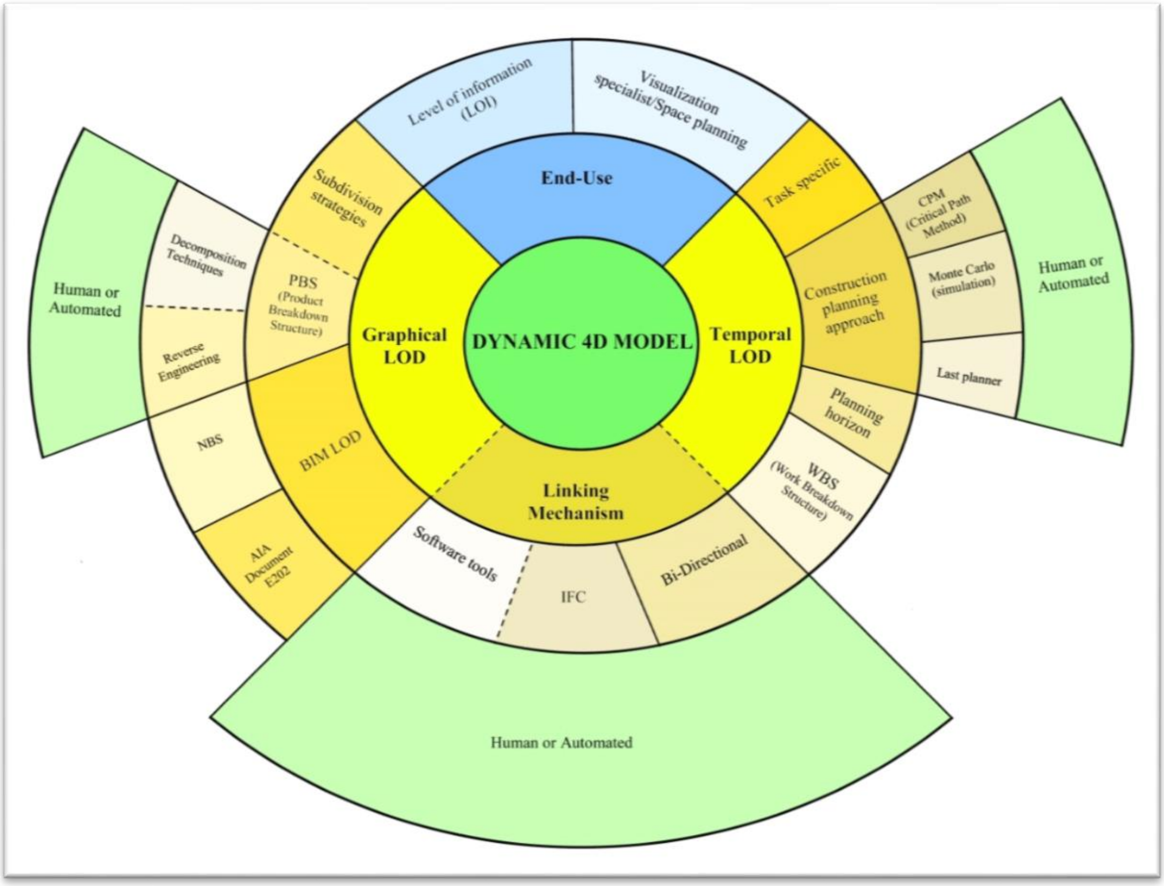


Figure 2 Conceptual Framework for dynamic 4D simulations
(Source: Butkovic and Heesom, 2017)

The questionnaire was developed for data collection in order to explore the possibility of implementing the proposed framework. This is an explorative research where the suggested framework is built around the technologies that are already in use in the construction industry. As the developed framework includes four specific areas such as a graphical LOD, temporal LOD, linking mechanism and end of use, these are divided into subsections in order to enhance construction planning and 4D attributes. The survey form was developed to examine if the applied tool had addressed each of these issues.

The developed framework is a party of a larger study therefore the findings of the survey should explore the current level of BIM implementation within the business processes in the organization and the level of use of 4D modelling.

2.2 Survey analyses

The data received from the questionnaire survey comprised of responses from of a range of professionals who were categorized into those whose specialism was BIM, those who were designers, project planner/management and surveyors. This gave a cross section of those who currently utilize 4D BIM for a range of applications. It is becoming clear from the results of this survey that the development of 4D models is falling under the responsibility of the BIM specialists more than the construction planner. This itself is worthy of note as from the early days of 4D development, it was hailed as a tool to support construction planning and specifically the construction planner. In order to produce a 4D simulation that contains the appropriate level of detail input would be needed from the construction planner and the construction management team to specify the LOD_{ti} and, if the geometry is to be divided or grouped to give a more realistic simulation, then a construction strategy/methodology would be required to support updates to the 3D geometry.

The ability to generate more ‘realistic’ simulations of the construction process is controlled by the ability to a) view realistic graphical representations of individual objects during construction and b) better control the time between state changes of the 4D model (LOD_{ti}) which then has an impact on how individual geometric objects from the BIM are subdivided. The graphical LOD of the BIM objects in the design model will play a part in governing the representation of single objects in the 4D simulation. However, some previous work has identified that for the purposes of site logistics planning and management, a low LOD of geometric objects is adequate (North *et al*., 2003). The overwhelming response from the questionnaire noted that the ability to subdivide the geometry to show a more granular level of progress in the 4D simulation was beneficial. Relating this to a schedule with a higher level of detail will then provide a more detailed 4D simulation which, from the results, planners see as beneficial during logistics planning of site operations.

3 Framework validation

The step forward was to present the framework to the targeted industry practitioners so as to validate the components and processes. The developed conceptual framework was designed on literature findings and the questionnaire analyses provided information to advance the framework for specifying the LOD of 4D simulation (LOD_{4D}). However, it was considered crucial to verify if the requirements identified are accurate and inclusive. By choosing six professionals of the industry specialists user evaluation interviews were carried out in order to validate the framework requirements.

The chosen group for the framework validation was required to contribute with their assessment if the framework fit for their companies’ purposes. The researcher started with the sending emails to potential participants in order to spur their involvement in validation process. First email enclosed a short explanation of the survey analyses and critical results. If the chosen expert agrees to take part in validation stage the expert would be introduced with developed framework and all justifications for the framework design. The next step was to agree on the interview where in live text conversation the participant gave his opinion of the framework, possible implementation, and the idea of the framework improvements.

3.1 General description

The industry practitioners involved in the validation project were: Virtual Design and Construction (VCD) specialists, Information BIM Mangers, Project Manager and Senior Consultant. The industry practitioners were targeted in the regard of working and being aware of the all aspects of the 4D BIM technology. Therefore, the responders are working in both the public and private sectors, they belong to different age groups and they are from India, Australia, the US and the UK.

Six semi-structured interviews were conducted with actors involved in the framework validation in the period of one month, depending on their availability. All interviews were performed over Skype or LinkedIn an each interview lasted approximately 45 minutes. The respondents agreed overall that the framework in general is valid and applicable to all construction projects where BIM is mandated.

4 Discussion

In this project some questions have been asked in order to trace the direction from practitioner' behavior during the project's lifecycle and the awareness on the subject. The reason for doing the validation interviews could be seen in the importance of showing that efficiency of some standards and classification systems in theory could be used in the real world. Framework validation interviews were done with industry actors as an aim to evidence the need of those who would use the framework in order to ensure effective task completion. The interviews were taken as transcripts which gives possibility of proper analysis even though the transcribing process is often time-consuming.

Live chat interviews allowed industry experts to give their insights on issues in a more private setting, enabling the researcher to obtain answers and ideas. One-to-one interviews assisted a more up close and personal idea, based on the experience of the interviewees themselves. Interviews verified to be a valuable instrument in bringing together different viewpoints on the subject that helped to confine and clarify some concerns raised during the previous phases of the study.

The table below portraits the reflections of the framework design in the participants' experiences and their current practices.

Table 1: Analyses of the framework validation interviews

Questions	Responses	Key findings from the validation (common themes)	Relation with the framework
Do you think that the framework as presented accurately addresses the needs of your company?	• *To a large extent yes.* • *Yes. It takes into account the 4D inputs necessary to design a suitable process.* • *I think it is a good start, however perhaps more consideration could be given to how the 4D programme will be developed with other project deliverables and design development.* • *Actually, for a good number of our clients, this is all they need but we get a biased sample as the companies that hire our services are pretty advanced in the practice.* • *I would say "yes", but I would like to make certain distinction. As software vendor, we are provider of BIM technology, not the receiver.*	Majority of respondents confirms that presented framework can address accurately the needs of companies where they work.	This encourages the author in effort to endure and address potential improvements.
If the AEC industry were to implement the framework as designed, what level of effort do you think it will require for you to adapt it or use it in your company?	• *The level of effort to implement the framework would be minimal. The level of effort to implement the information within the framework would vary depending on my clients. And would vary from much effort to a great level of effort.* • *This is a great question, but I'm not sure it applies what my company does is two things mainly sell software and sell consulting services.*	If the AEC industry were to implement the framework as designed, they would require minimal effort to do so on all BIM mandated projects but would also depend of the Client needs.	This encourages the author in effort to endure and address potential improvements.

	• *Very little effort, as many of the framework concepts, already exist and are established implemented (where they are implemented).* • *Well that's a difficult question because it is a framework not a specification - if you are saying all this will be set as mandatory and international or national standards will set the effort / granularity, then it could be quite involved.*		
Where do you think the level of detail in the 4D simulation should be specified?	• *In the EIR* (Employers Information Requirements) • *In the BIM Execution Plan and maybe at high level in the EIR* • *In Contract Specs or BIM execution plan.* • *into the design/engineering* • *In an Employers Information Requirements for a BIM project.*	In EIR (Employers Information Requirements) & in BIM Execution Plan	Framework should adopt the common theme.
How relevant do you think this approach would be to a typical construction project?	• *Very relevant* • *It is not relevant to a 'Typical' construction project....yet. Here in Australia BIM is becoming more frequently used however the adoption of 4D planning is minimal.* • *Very relevant* • *The framework will be relevant for ANY project using BIM, some industries will see larger relevance (and benefit) - for example, buildings, single location projects.* • *Very relevant assuming the project had a reasonable complexity.*	Relevance of the framework approach in construction projects was confirmed by all interview participants.	Framework should adopt the common theme.
How might you use that framework on a construction project where you need 4D?	• *We are almost following the same framework. We do design the 4D in the same lines.* • *To help ensure the 4D requirements are considered.* • *I think your framework is a very good method of helping a team de-mystify how 4D should fit in to the bigger picture BIM delivery. I think it would have to be further refined on a 'case-by-case' basis depending on the particular project requirements.* • *You use the point in construction that is mentioned in your framework to determine the LOD combination that gives highest ROI (return of Investment) then you follow the rest of the framework.* • *I would use it to change the methods of planning and scheduling and specify the requirement for 4D more clearly, to gain measurable benefits.* • *I would expect a supplier to provide a process map for managing inputs and outputs for 4D, in specifying 4D in EIRs you could look at sources of information and confirm responsibilities and roles in 4D modelling.*	The framework suggested could be used on 4D construction projects to change the methods of planning and scheduling by specifying 4D requirements clearer and processing inputs and outputs in EIRs and verify responsibilities and roles in 4D modelling. However, it needs to be refined on a case-by-case base and related to specific project requirements.	Framework should adopt the common theme.
How might you improve the framework?	• *By putting comparability between the software.* • *Consider CBS (cost breakdown structure) and risk* • *An LOD can be referenced for model LOD; however, I have not yet seen a document that outlines 4D schedule LOD. This could be a very good idea. Potential some form of high-level guidance of what would be expected for various levels of detail in the schedule would be good to support the framework.* • *You split LOD into graphical and time, where is really should be Model and time, and then model should be split to geometry detail, parameters/data, and functional visualizations (crane reach, caution area, etc.).* • *I think showing it as an input - process - output model - SIPOC analysis and showing the level of maturity in projects against it and defining if the client or supplier is responsible for the input source. Adding logistic pathways and cost level of information to the graphical may help clarify the inputs better.*	Potential needs to include CBS (cost breakdown structure) and high-level guideline to address various LODs in a 4D schedule.	Framework should adopt the common theme.

According to interviews, the framework takes in account the 4D imputes necessary to design the suitable process. In their opinion the level of effort to implement the framework would be insignificant in all BIM mandated projects, as many of the framework concepts already exist, and they all agree that the necessary components are included. However, for the companies who are not BIM ready or at lower levels of implementation the effort would be significantly larger, this is due to the fact that the AEC industry is not BIM matured evenly. This could be seen in the main survey of the study where the question of the time interval of the changes in the simulation in respondents' answers in total has only 6.4% for the hourly scheduling and 44% for the daily scheduling. However, 87.2% of respondents agree that if a 4D model shows more details it can improve the identification of potential conflicts and clashes and they should have ability to change the details of the 4D directly within the software. If the progress of UK BIM Level 2 is based on the maturity of BIM level 1, and BIM Level 2 the main requirement is to progressively capturing and enunciating information to support the whole lifecycle management of assets (McPartland, 2014), therefore hourly sequencing need more attention from industry practitioners in order to resolve issue regarding the absence of appropriate LOD.

It is based on validation and building on the initial conceptual framework, that the broader obligation of this work proposes to create a new methodology for the specification of the LOD of 4D simulations. The overall 4D LOD (LOD_{4d}) is a unification of Level of Graphical Detail (LOD_g) and the Level of Temporal Detail (LOD_{ti}) which details the time required in the simulation between state changes. However, the graphical LOD should be a combination of the detail of the geometry representing the final product (i.e. the BIM LOD) and the Level of Detail of granularity (LOD_{gran}), which depicts how the object should be decomposed during the linking process.

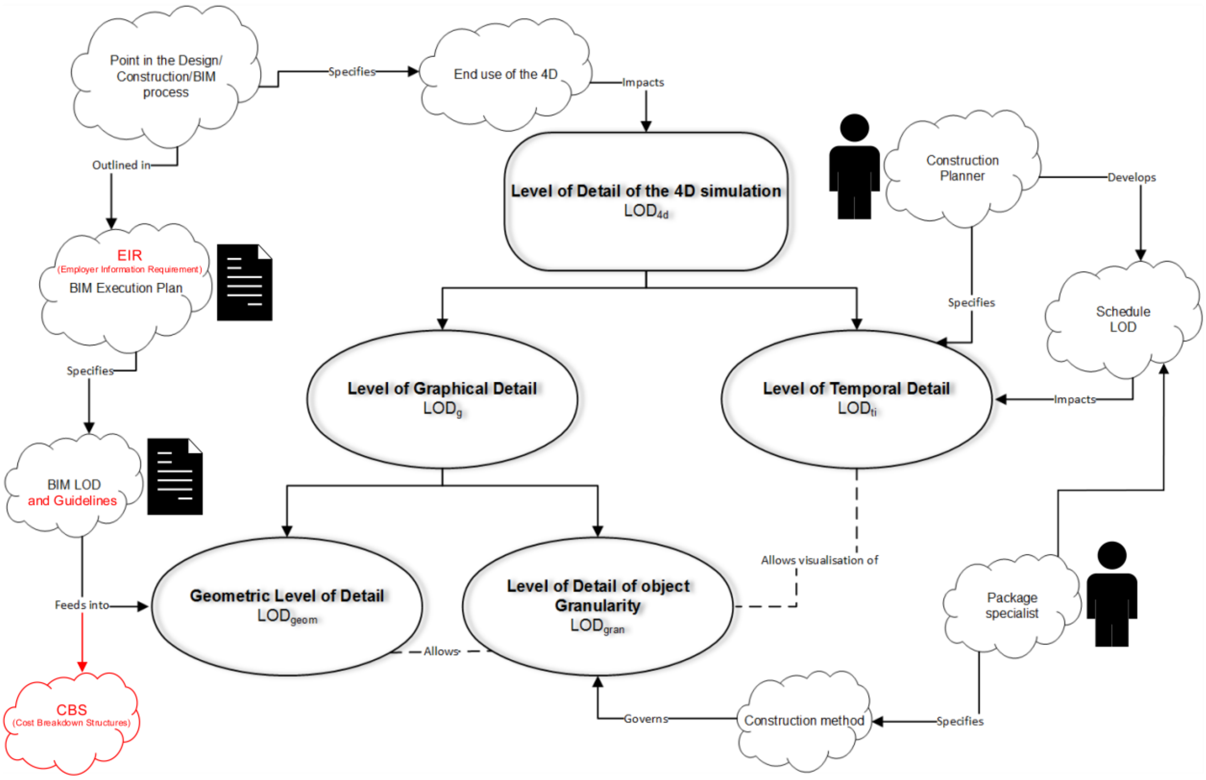


Figure 3 Framework for specifying the LOD of a 4D simulation (LOD_{4D})

5 Conclusion and future work

This paper has provided detail of the validation of the framework for more dynamic 4D simulations which is a part of wider research. This work has presented a conceptual framework and built on the research survey and the validation of the theoretical framework a Framework for specifying the LOD of a 4D simulation (LOD_{4d}) was created. The research indicates that the framework as created could be beneficial to the industry as the framework addresses the current industry needs to a high degree. Nevertheless, the findings from literature, the results of the main survey and the interviews results initiated further update of the framework. The framework should assume automation of progress monitoring supports. However, currently some 4D software incorporate tools providing decomposition of geometric objects within the produced environment, by permitting the subdivision of geometry although this is still a very manual exercise and not dynamically linked to the specification of a LOD_{ti}. The future work should include the implementation of the proposed framework in the real time construction project in order to provide more authorized use of 4D simulation.

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Glossary

Terms	Meaning
3D	3-dimensional shows a virtual model of the building element in the construction.
4D	4-dimensional 3D plus time in the construction activity schedule.
BIM	Building Information Modelling is a set of processes for creating and managing information on a construction project throughout the project lifecycle.
BIM LOD	BIM Level of Development is a concept that defines the content and consistency of BIM elements at different phases of the construction project.
LOD_{4D}	LOD of a 4D simulation is a unification of LOD_g and LOD_{ti} which details the time required in the simulation between state changes.
LOD	Level of Detail is the main stage of information; the model must include the different phases of a project lifecycle according to its use. LOD purpose is to model an object with the most appropriate geometry and representation agreed with a specific objective of analysis. LOD essentially defines model evolution.
LOD_g	Level of Graphical Detail is the geometry (graphical) information of the model during the course of the construction project.
LOD_{gran}	Level of Detail of object geometry “granulated” (divided into smaller segments to provide more dynamic 4D simulation).
LOD_{ti}	Temporal Level of Detail is the non-graphical level of information during the construction project. It is the time period required between state changes in the model during the simulation. Level of Information considers a quality of semantic parts of an object.
UK BIM Level 2	To clearly define what, when and how information for any construction project should be created, managed and shared. BIM protocol needs to be followed in a pre-construction, construction, cooperative work which means to share data and work on one model. At Level 2, COBie (Construction Operations Building Information Exchange) is used and it is usually represented as a central spreadsheet where non-graphical data can be stored, shared and updated throughout the whole of the construction project.

References

Butkovic, B. and Heesom, D. (2017) Towards A Framework For Multi-LOD 4D BIM Simulations. *International Research Conference 2017*. University of Salford, 11-12 September, pp. 578-586

McPartland, R. (2014) *BIM Levels explained* [blog entry]. [Accessed 2 November 2018]. Available at: <https://www.thenbs.com/>

Mordue, S., Swaddle, P. and Philp, D. (2016) *Building Information Modeling for Dummies*. West Sussex: Wiley

North, S., Winch, G.M., Dawood, N., Heesom, D., Kelsey, J., Sriprasert, E. and Mallasi, Z. (2003) *Technical Evaluation: VIRCON Task 12 Report*, Manchester Centre for Civil and Construction Engineering UMIST, a VIRCON report

Winch, G.M. (2010) *Managing Construction Projects.* 2nd ed. West Sussex: Wiley

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THE NEED FOR MULTI-LOD 4D SIMULATIONS IN CONSTRUCTION PROJECTS

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EDITOR: Kumar B.

Bogdan Butkovic, PhD Candidate,
Faculty of Science and Engineering, University of Wolverhampton, UK;
B.Butkovic@wlv.ac.uk and https://www.wlv.ac.uk/

David Heesom, Dr., Reader in Building Information Modelling (BIM),
Faculty of Science and Engineering, University of Wolverhampton, UK;
D.Heesom@wlv.ac.uk and https://www.wlv.ac.uk/

David Oloke, Dr., Senior Lecturer,
Faculty of Science and Engineering, University of Wolverhampton, UK;
D.Oloke@wlv.ac.uk and https://www.wlv.ac.uk/

SUMMARY: *The increasing application of BIM processes and technologies has facilitated an increase in the use of 4D (3D+Time) simulations of construction projects. Previous research has acknowledged the benefit of 4D models in the project planning and construction phases enhancing communication between construction teams and avoiding unforeseen conflicts during the build process. The development of BIM has spurred a deeper understanding of the issues surrounding Level of Development, Level of Information (LOI) and Level of Detail (LOD) pertaining to the graphical detail and non-graphical information of the static geometric design model. However, to date there is limited research thoroughly investigating the issue of LOD within 4D applications. This work presents an ongoing study to derive a framework for the development of more dynamic 4D simulations incorporating discrete forms of LOD. Level of graphical detail (LOD_g) corresponds to the graphical detail of the model geometry and also the 'granularity' of the geometry required for dynamic 4D production, whilst the temporal level of detail (LOD_{ti}) relates to time period required between state changes in the model during the simulation. In order to support the development of the framework, an industry-based survey was conducted to assess the application of 4D, subsequent issues and use cases around levels of graphical and temporal details to improve dynamic 4D simulations. The work concludes with the development of a framework and schematic to support the specification of the LOD of a 4D simulation (LOD_{4d}) throughout the various phases of a construction project.*

KEYWORDS: *4D, Level of Detail (LOD), BIM, Simulation*

REFERENCE: *Bogdan Butkovic, David Heesom, David Oloke (2019). The need for multi-LOD 4D simulations in construction projects. Journal of Information Technology in Construction (ITcon), Vol. 24, pg. 256-272, http://www.itcon.org/2019/14*

1. INTRODUCTION

Building Information Modelling is now a crucial part of the construction process, where the creation of a 3D geometric model starts early in the development cycle (Mordue *et al*., 2016). The level of development (LODt) defines the precision of the 3D elements and the quantity of non-graphical information contained in each element accordingly as the model evolves (Bedrick, 2013). The graphical Level of Detail (LOD) within a BIM is defined and based on individual elements, as well as the development of the elements all the way through the project from the conceptual design to the highest level of the representation (as-built). Whilst BIM has allowed a greater flow of information throughout the lifecycle of a construction project it has not completely resolved this issue of lack of sufficient design and construction information at the planning stage. Winch *et al*. (1998) noted that the lack of information at this stage was a key problem affecting effective construction planning. The issue of LODt has received attention from BIM researchers and practitioners including The American Institution of Architects (AIA) who developed principles to assist communication during the construction project. AIA E202 is a document providing guiding principles about the models, indicating the relationship of the level of development with the proposed use of the model at every stage of the project (Kensek, 2014). In the UK, the PAS1192 documents (BSI, 2013) and the NBS Toolkit (NBS, 2015) provide guidelines and templates for the LOD requirements at various stages of the design and construction process.

Construction planning is a critical element of a project ensuring that tasks are completed in a logical and timely manner. At the present time the development of the schedule is undertaken by the construction planner who has the expert knowledge to derive logic between relationships and also the ability to breakdown tasks into sub processes as the construction sequence progresses to provide a greater level of information to the team (Sigalov and Konig, 2017). Winch (2010) further discussed the evolution and increasing detail of tasks through the Work Breakdown Structure (WBS) at key stages of a project. Noting that as the WBS increased in granularity during the design, planning and construction phases, so can the Product Breakdown Structure (PBS), providing the opportunity for these to be linked together to provide a 4D simulation. The level of detail of a construction schedule is defined by various authors who provide underlying nuances, essentially follow the same philosophy that detail increases as the project design and construction continues. Jelen's schedule levels (Humphreys, 1991) progress from Level 0 to Level X moving from whole project level to individual task specific sub schedules, but noting that there is no universal specified number of levels. Various other protocols exist to support the definition of the level of detail of the construction schedule including the use of numeric levels and descriptive levels of detail (AACEI, 2010).

Trani *et al*. (2015) highlighted that the Level of Graphical Detail of a 3D (BIM) model varies during the design and construction of a project, and these can be used for various planning activities during each stage. Additionally, levels of detail must correspond to the industry needs' and the estimated usage of the model at different phases of the construction project (Boton *et al*., 2015a), deriving a higher or lower degree of realism for the 4D simulation as the need arises. Faloughi (2017) identifies that the production of 4D is not a one off event, and different simulations will be generated at various stages of the project lifecycle. Each of these may require a differing LOD. This specific area of research to understand the alignment of schedule, 3D and 4D Level of Detail has attracted a limited amount of attention and is subsequently the focus of this study.

2. 4D BIM AND LEVEL OF DETAIL

Since the late 1990s, a wide range of research has been undertaken in the field of 4D modelling including the application for collaboration, space planning and the use for health and safety (McKinney and Fischer, 1998; Aouad *et al*., 2012). The use of 4D adoption is increasing within the construction sector with upper management beginning to see the potential benefits of using it as a viable planning tool (Gledson, 2015). Issues of LOD around the 3D geometric (BIM) model during design and construction have received attention both from practitioners and researchers. However, even with a great deal of attention, Grytting *et al*. (2017) noted that there were still issues to be resolved as a number of models were delivered with a higher or lower LOD than necessary leading to change orders. Whilst the LOD protocols for the design model provides guidance to those interacting with the 3D geometric aspect of the final design, there has been little work presented to fully understand and define the specific level of graphical and temporal detail required for 4D simulations throughout the construction process. As such the LOD for 4D is still not well defined nor is the way to develop a simulation with a specific approach to LOD management (Guevremont and Hammad, 2018).

Both the graphical and temporal detail of a 4D simulation must be such that it can facilitate effective managerial decisions and thus construction processes during the project (Guevremont and Hammad, 2018). Furthermore in order for a 4D simulation to remain useful throughout the duration of a construction project, it must be continually used, evaluated and refined as the project progresses (Umar *et al*., 2015). This continued maintenance of the 4D simulation is subsequently seen as a limitation to the implementation of 4D during the construction process (Romigh *et al*., 2017). The use of 4D changes throughout a project, as does the use of the entire BIM dataset. Furthermore, the view of the BIM dataset can vary depending on the viewer. To resolve this phenomenon, Tolmer *et al*. (2017) propose a Level of Abstraction (LOA), which identifies the relevant objects that need to be considered for the specific use of the BIM. This concept may be something that could be applied to 4D to propose the specific LOD for use cases.

Trebbe *et al*. (2015) highlight how 4D BIM can be used to understand complex interconnections between different stages of construction work in any project. The individual 3D elements within the 4D simulation allow project stakeholders to view the what, where and often how of the construction process from design, procurement and construction schedules. Aouad *et al*. (2012) postulated that more dynamic 4D simulations were required in order to achieve more reliable outcomes, when used in the planning process. Boton *et al*. (2015b) also noted that levels of detail of the graphical models used during any 4D simulation must correspond to the industry needs' and the usage of the simulation at different phases of the construction project. Faloughi (2017) supported this notion whilst also proposing questions such as whether the BIM models are developed enough to match the level of detail of the schedule or are too detailed for the purpose of the 4D simulation. Building on these issues, it has also been acknowledged that any specification of 4D LOD should manage both the graphical level of detail and the temporal level of information, in order to deliver realistic and more reliable 4D simulations (Tolmer *et al*., 2015). However, little has been undertaken to formalize these issues.

According to Aouad (2012), in order to assist more dynamic 4D, the 3D model creators need to have approached the geometric composition in such as way that it can support the 4D activities and 3D models have to be organized into work components to match the level of detail in the schedule. However, in many cases the initial design model is often not created with the intention for it to be used for planning or control purposes and often leads to the contractor generating a new model for the purpose of developing a 4D simulation. It is at this point that they may consider the LOD required to produce a viable 4D model, subsequently updating the representation of geometric objects (Lui and Li, 2013). As part of this process the granularity of the geometry of the 4D simulation can require either the subdivision of elements or the aggregation of elements to create the geometric portion of a '4D Object'. As early as 2008, Tulke *et al*. (2008) proposed an algorithm based approach to split geometric objects within an IFC file into portions away from the BIM/CAD authoring tool for the creation of more dynamic representations of construction within the 4D software environment. This is now a more commonplace capability in some commercial tools, as is the ability to combine individual elements to create an aggregated group for linking. This variable approach of linking objects provides the ability to better satisfy any 4D LOD requirements (Guevremont and Hammad, 2018). However, there is still an explicit link between the LOD of the BIM geometry and the requirements of the 4D LOD. For example, to facilitate the visualization of a high schedule LOD, a highly detailed geometric model may be required. A typical example would be a 4D showing the installation of cable trays where installation of individual hangers was to be shown. These geometric objects would need to be modelled in the BIM to be available to inclusion in the 4D simulation.

Boton *et al*. (2015b) presented a case study of the development of 4D models at different stages of the design and construction process. However, the development of the Level of Detail within this project was mainly focused on the graphical detail of the design model. Models were created in accordance with the AIA LOD 100-600 series using a range of software tools and then 4D simulations were created. The work did highlight the changes required for the resolution of the plan at each stage and this was appropriate for the detail of the graphical model, also noting that LOD required for the construction phase is higher than the LOD needed in the pre-construction phase (Kriphal and Grilo, 2012). On the other hand, it did not resolve the critical question of decomposition of construction product elements for the generation of more dynamic 4D models and whether this is also required to change to meet the needs of project planning through the various phases of the lifecycle of the design and construction. The study did conclude that a single graphical LOD is not adequate during the construction phase and that different levels of development were needed for visualization and coordination, depending on the 4D model purpose and the specific construction problems that occurred during construction and modelling processes. This view is supported by McGeorge and Zou (2013) who note the understanding of complex models could be aided by the technique of model decomposition that subdivides models into smaller significant sub-models in order of their conception.

It is apparent that in 4D models, LOD specification should manage graphical levels of detail and the temporal level of information in order to deliver realistic and more reliable 4D simulations (Tolmer *et al*., 2015). This is something that was highlighted by Guevremont and Hammad (2018) where two 4D simulations were implemented on a case study project. The low LOD was based on low schedule detail and the higher includes more detailed schedules and more detailed geometric breakdowns. A medium LOD could also be used for workspace allocation. The work also notes the important issues of the time step used in the 4D simulation and this is based on data available in the schedule LOD and the ability to change between the low and high level of detail as required. This becomes a critical issue for 4D simulations moving forward as the ability to step between multiple LODs' within the same simulation session will provide a more comprehensive usability.

The absence of an approach to define and specify the level of detail in 4D simulations for effective evaluation of the construction process was highlighted by Heesom and Mahdjoubi (2003). They indicated that developing more dynamic 4D simulations would provide more accurate and more realistic outcomes (Heesom, 2006). In order to provide a more dynamic 4D simulation, the Level of Detail of the 4D simulation (herein termed LOD_{4d}) must manage both the graphical level of detail (herein termed LOD_g) and the temporal level of information (herein termed LOD_{ti}). The LOD_g is key to providing the end user with enough graphical information of the element due to be constructed. As an example, Han and Golparvar-Fard (2015) suggest that the lack of detail in the 3D BIM used during the pre-construction planning phase is not sufficient enough for tracking the progress on individual element bases but can provide an overview of the process. In addition to the detail of the graphical element, the LOD_g also needs to encompass the granularity of the object(s) being simulated. In this case the granularity is defined as how a single 3D geometric BIM object is potentially sub-divided into constituent parts or aggregated for linking to individual tasks in the 4D simulation, providing a more accurate reflection of the dynamics of construction sequence. The LOD_{ti} within a 4D simulation is a critical factor as this details the time period between state changes in the simulation required for each task i.e. 1 day, 1 week, etc. Further comprehension of the interrelationship between these factors will allow specification for elements within the construction process.

2.1 Existing software tools for 4D BIM

As 4D has evolved and become more prolific through the increasing use of BIM technologies and subsequently 3D digital models, a range of software applications that support 4D modelling have come to market (Table 1). These are part of suite or stand-alone third party applications. The functionality of these tools varies however the core ability is the same whereby 3D components are linked with temporal data through either linking on an individual or group basis. Generally this is undertaken manually, however the functionality of these is evolving by allowing the link to be developed using more automated algorithms using the attribute based data attached to the 3D elements.

As BIM evolves and more 4D tools appear to the market some the functionality of many appear to converge. The basic premise of linking 3D to schedule data is the same throughout all of the above. Many tools have both the ability to import schedule data from most prominent planning tools, including Primavera, Microsoft Project and Powerproject, but are also now providing the ability to generate construction schedules within the 4D software tool. The strengthening of this approach in the future may well see an increasing up take of the 4D paradigm as it will potentially remove the 'linking' stage in the development of 4D. In addition, the ability to import a wider range of 3D geometric formats is becoming a key factor in the tools. Whilst it is acknowledged that most have the ability to import the IFC file format, the ability to import native, proprietary formats appears to be a key area of development. In addition, tools such as Vico have to ability to interact with the BIM Collaboration Format (*.bcf) file type.

With respect to the level of detail capabilities, all of the existing tools have the ability to change the time between state changes of the 4D simulation. These can range from using minutes, hours up to months or also provide the ability to show the progress of the task as a percentage of the time completed. However, it is not possible to have multiple temporal state changes within a single 4D simulation session. For example, in one complete session it is not possible to view progress on a daily basis, then switch to an hourly basis then to weekly basis. This would need to be undertaken as three separate simulations with manual intervention. All of the software tools have the ability to link multiple geometric objects to a single task, or indeed group the objects together and link to a task(s). However, not all of the tools have the ability to subdivide the geometric objects from within the 4D environment. This aspect is critical to developing a level of granularity and a subsequent higher level of detail for the simulation to show greater detail in the process of construction.

Table 1: Current 4D software applications

Company / Tool	Description	Linkage	LOD capabilities	
			Temporal	Graphical
Bentley / ConstructSim Planner	Provides Project and analyse wise schedule simulation. Import 2D and 3D design files difference sources	Importing and connecting schedule information from Microsoft Project, Excel or Primavera. Reviewing interfaces (clashes) and viewing and analysing schedule simulations	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects but not able to subdivide imported geometric objects within the software environment
Autodesk / Navisworks	Supports various numbers of BIM formats and has overall very good visualization capabilities Permits the importation of schedules from a variety of sources	Supports manual and automatic linking to imported schedule data from variety of schedule applications Allows the user to join the items in the model with the tasks and simulate the schedule	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects but not able to subdivide imported geometric objects within the software environment
Innovaya / Visual Simulation	Combines BIM objects with planning activities to complete a 4D construction. Generates simulation of construction process	Increases the project communication, synchronization and logistic scheduling. Links 3D design data in DWG with Microsoft Project or Primavera	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects but not able to subdivide imported geometric objects within the software environment
Synchro Software Ltd. / Synchro PRO ** *(Note that Synchro was acquired by Bentley Systems in June 2018)*	New 4D tool with improved scheduling and project management	Covers risk and resource analyses features and include built in tools to visualize risk, buffering and recourse usage in addition to 4D visualization	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects Ability for geometric objects to be subdivided within the software environment
Elecosoft / Powerproject BIM	4D planning to combine 3D planning and scheduling linking the project plan and model together in one application.	Users are able to import the IFC models in the project plan with full 3D visual impact and to create milestones and baselines to simulate projects.	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects Ability for geometric objects to be subdivided within the software environment
Vico / Schedule Planner and 4D Player	Part of the Vico Office Suite providing the ability to run full simulations of the construction process including 4D and 5D	Uses Line of Balance planning to link to 3D geometric model	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects for link to LOB tasks but not able to subdivide imported geometric objects within the software environment
rib software / iTWO 4.0	5D cloud based enterprise platform that also encompasses the ability to include schedule data for 4D simulation	Import model and develop schedule of activities within the software.	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	N/A
ACCA Software (Italy) / usBIM.gantt	4D BIM project management with project management and scheduling 4D time simulation.	Allows project managers to assign a time-line related property to each components of the BIM model in IFC format in order to see the entire construction process in open formats.	Ability to change time between 4D state changes. Not able to change temporal steps / have multiple steps during a simulation.	Able to group objects for linking to tasks

3. RESEARCH METHODOLOGY

The specific issue of the LOD within a 4D simulation still requires attention. Primary research has been undertaken to understand issues surrounding the implementation of 4D within the construction industry around the world including the UK, Australia, the US and Iraq (Gledson and Greenwood, 2016; Kim *et al.*, 2016; Hamada *et al.*, 2017; Wong *et al.*, 2011). However, these efforts have focused on the implementation of 4D as it currently stands and did not specifically focus on the issue of the requirements of Level of Detail (LOD_{4d}) of the 4D simulation. Consequently, this study adopted the approach to solicit the opinions of expert users from the industry in order to develop deeper knowledge of the requirements of more dynamic 4D simulations. From this, a framework is proposed to provide an approach to specify the LOD during the planning process and subsequently allow multi LOD simulations to be developed within the 4D session.

An online questionnaire was developed with a survey period between Q3 of 2017 and Q2 of 2018. The target sample population of the study was those who actively engaged in using 4D simulations on a range of construction projects across a section of companies identified from industry case studies. A total sample size of 101 questionnaires were issued with 82 responses being received. Of these responses a total of 61 fully completed questionnaires were received (response rate of 60%) and treated as valid for the purposes of analysis.

The initial part of the questionnaire sought to gain a level of demographic information on the responder, the type and sector of company worked for and the nominal size of the projects the company engaged with. The purpose of this was to identify the role of the participant and to ascertain if any of the results around the use of 4D, and particularly the issue of LOD, was affected by the nature of the company and the type of construction work engaged in. This also included an element of the survey that investigated the role of BIM in the company and particularly the usage of technology to support the BIM process. This focused on the 4D software tools and the project planning tools implemented to provide a backdrop of technology usage. The second section of the questionnaire elicited deeper information on the usage of 4D both from a technological standpoint of who took responsibility for the creation and also how the 4D simulations were used once generated. Building on this, it went on to determine what graphical and temporal level of detail (LOD_{ti}) was used at the moment for each of the use cases of the 4D simulation. The final section of the questionnaire presented the responder with a range of typical construction tasks and asked them to identify to what LOD_{ti} they believed would be most appropriate for that task(s). This section aimed to derive whether there was a need to obtain a range of LOD throughout the lifecycle of a 4D simulation depending on the work package being undertaken at any discrete point. Descriptive statistics were used to develop an overall picture of the use of 4D and the issues surrounding the Level of Detail, including the potential of the 4D simulation to show the construction process at a range of graphical and temporal level of detail. This would then inform and support the development of a framework for the creation of 4D simulations that contain multiple LOD, which can be implemented for the full range of the construction process.

4. RESULTS OF THE QUESTIONNAIRE

4.1 Responder profile

The first stage of the survey analysis was conducted using descriptive methods to gain a level of understanding of the demographic of the responders and the range of work they currently undertake (Figure 1). The highest number of responders fell into the category of BIM Manager/Coordinator/Information Manager (42.6%; n=26), followed by Project Management / Planning (27.9%; n=17), Lead Designer/Engineer (14.8%; n=9), Other management (11.5%; n=7) and Surveyor (3.3%; n=2). The majority of those responding to the survey had worked in the industry for over 15 years, with the median working time having been between 4 and 10 years. The BIM Manager/Coordinator/Information Manager roles showed the highest number of years worked in the sector with most having experience of between 10-15 years. It could be inferred from this that those in the BIM roles have moved into those roles from other specialisms as BIM has become more widespread.

The majority of the respondents to the survey were currently working in the commercial construction sector (59%), followed by civil/infrastructure (34%) and residential (7%). Furthermore, the results demonstrate that the responses came from an even cross section of SME and larger companies with 34% also coming from 'small companies' comprised of 50 people or less.

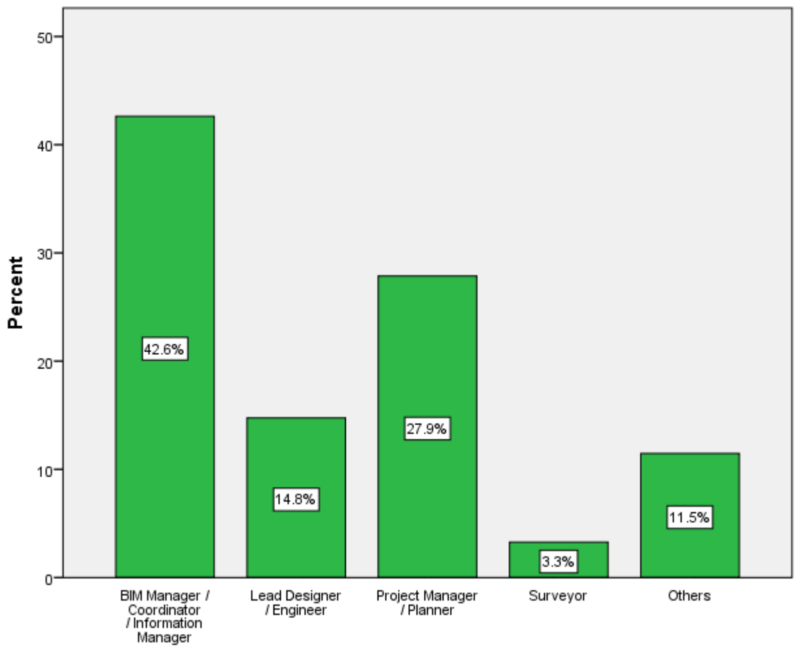

Figure 1: Demographic role of respondents

Within the cross section of responders 92% had engaged in projects where BIM had been used. 75% of these identified the experience they had as being at the UK BIM Level 2 standard and the majority (66%) had been working at this level for between 3-5 years. On the issue of software, the results mirrored those reported annually in the NBS BIM Survey (NBS, 2018), which highlighted Autodesk Revit and Graphisoft ArchiCAD as those most used on BIM based construction projects. However, information was also garnered around the use of 4D simulation tools with Autodesk Navisworks proving the most popular, followed by Synchro and finally Bentley ConstructSim.

4.2 4D modelling issues

The second phase of the questionnaire sought to develop further understanding of the experience of participants with respect to 4D usage and also elicit knowledge around the perception of how 4D simulations are developed to show the more dynamic nature of the construction process. In terms of more 'traditional' 1D (time based) project planning, a range of software applications were used with the most popular being Microsoft Project, followed by Primavera, Powerproject and then others which included which included tools such as Microsoft Excel. Of the responses received, it was shown that 62.3% had made use of 4D BIM on construction projects and where it had been used, it had been predominantly applied for purposes of communication with either the client or between contractors and sub-contractors. Other uses included logistics or to enhance the actual planning phase to support development of what-if scenarios during the planning stages (Figure 2). The results broadly concur with those found by Gledson and Greenwood (2016) who found similar uses for 4D which can thus provide a level of credence to the cross section sample within this study.

In order to further investigate this aspect of 4D development, a correlation analysis was undertaken using Pearson coefficient between the usage of 4D BIM and those responding. This demonstrated there is a strong correlation between using 4D BIM for "Communicating the plan to client" ($r= +.534$), and BIM Managers / Co-ordinators / Information Managers while a strong correlation was presented between Project Managers / Planners and using 4D BIM for "Working package conflicts detection" ($r= +.208$) and "Site logistic or space planning" ($r= +.549$). The result could impact on the LOD_{4d} and some of the discussions noted in the previous section whereby it potentially points to the BIM Managers/Coordinators would be involved in the development of lower LOD_{4d} whereas the Project Managers would be involved in higher LOD_{4d}. This could be as expected, however it does have potential to require the project managers to engage in software tools for the development of high LOD_{4d} simulations using decomposition techniques etc.

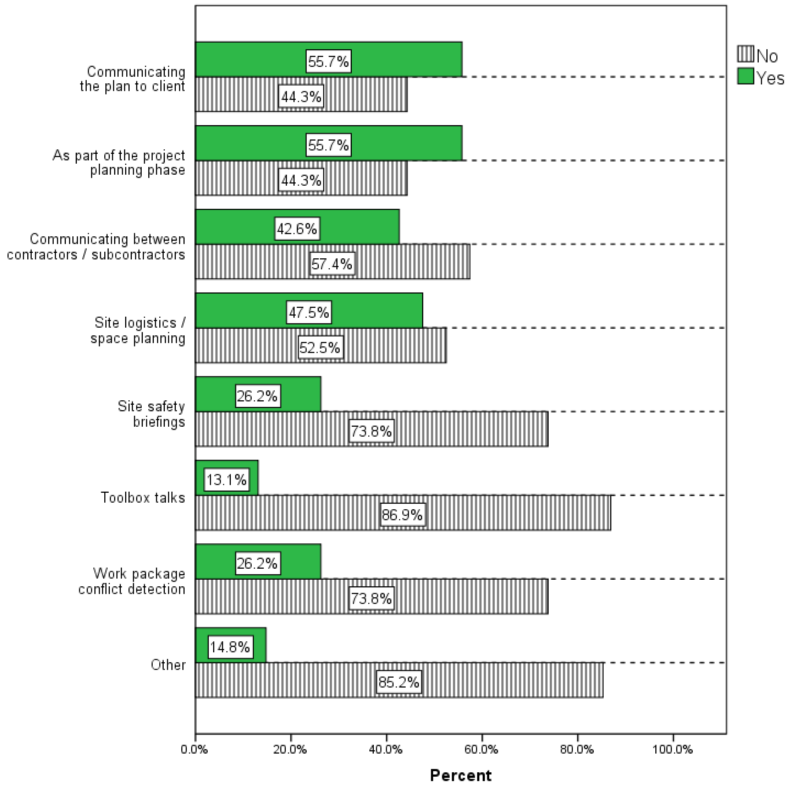

Figure 2: 4D BIM usage in construction projects

As 4D BIM becomes more prominent in construction projects, the responsibility for development of the 4D simulation is also now becoming more fluid. During initial research in the early 21st Century, it was postulated that the construction planner would undertake the development of the 4D simulation and the associated software would become part of the planners' toolbox (North *et al*., 2003). However, as part of this study it was initially hypothesised that as BIM is becoming a specialism and is developing new roles within the industry, so the development and creation of the 4D simulation is falling under the remit of the 'BIM Coordinator / Manager'. The responses to the questionnaire demonstrate that 70% of 4D simulations were actually generated by either BIM (or CAD) technicians or BIM Coordinators / Managers or BIM/4D specialists. 30% were developed by Project Managers or Project Planners. Whilst this still leaves a level of ambiguity, as the initial project schedule of activities were developed by project planners, the development of the 4D and the linking of tasks / sequences to 3D geometric objects was still left to others. Somewhat contradicting this, 68% of responders were of the opinion that the generation of the 4D simulation should be the role of the project manager or project planner. This dichotomy of 4D BIM responsibility is something that requires further in depth consideration outside of the scope of this study but could be attributed to lack of knowledge of current 4D software tools or inability to use current software packages or the lack of direct integration between traditional temporal based planning tools and the 3D technologies associated with the BIM process. With respect to any future LOD_{4d} it could be questioned if the BIM coordinator/manager has the expertise and knowledge of the construction process to develop the 4D model. If not then input would still be required from the planner and/or construction manager to specify the LOD_{4d} from which the simulation could be developed.

Current 4D BIM software technology provides the ability to vary the LOD_{ti} i.e. the time between state changes in the simulation. This can be set to specific intervals within all of the software tools noted in the previous section of the paper. Additionally, several of the existing software tools now provide the ability to either group individual objects or subdivide the geometry of 3D model within the 4D environment to provide the user / planner to develop a more detailed 4D simulation (for example sub-dividing a complete slab generated as 1 geometric object in the BIM authoring tool into subsections for the purpose of planning). This ability to subdivide the geometry to provide greater detail and granularity of the 4D model is critical and 95% of the questionnaire responders agreed that the ability to undertake this provides the ability to produce a more realistic and useful 4D simulation.

However, it still remains an issue to have a single 4D simulation that has the potential to move between various LOD_{ti} as the simulation evolves without having to stop the process and re-specify the time between state changes. 61% believed that the ability to change the LOD within the 4D model was beneficial and could provide more flexibility to the end use of the simulation. The time between state changes varies for various tasks on various projects and is also a subjective factor depending on several variables such as the end use of the 4D model. In order to further understand this phenomenon, the questionnaire asked those who had previously used 4D simulations what LOD_{ti} had been applied. 41% noted that 1-week had been used as the value, 21% stated 1 month had been used, 21% had changed the 4D model on a daily or bi-daily basis and 7% had used the simulation to show changes on an hourly basis. One responder noted that *'…hourly is very common for management and proof of method in advance works'* and another noting that this sometimes changes to facilitate *'…live re-planning'* during a project. Specifically in the area of logistics planning and the use of 4D to alleviate clashes between trades and time space planning during the project, 91% stated that a higher level of graphical detail in the model (LOD_g) and a shorter time period between state changes in the 4D model (LOD_{ti}) were used to undertake a more 'micro' level of 4D. Interestingly it was predominantly the project managers / planners who had responsibility to specify time between state changes for the simulation (58%).

4.3 Example temporal LOD (LOD_{ti})

The responses highlighted above demonstrated that a significant number of the professionals identify the potential benefits of having varying LOD_{ti} within a 4D simulation with nearly two-thirds noting that often it is beneficial to have multiple graphical LOD (LOD_g) and multiple time based on LOD (LOD_{ti}) on a project. This could be particularly true for large projects where some elements may require more detailed planning to enhance issues such as site logistics. In order to gain further insight into this aspect, the third phase of the questionnaire provided a list of 28 nominal construction tasks, which could be represented in a 4D simulation, and asked the responders to note what they believed the optimum temporal stage change would be for each task. The level of graphical detail of the geometric objects was removed from this element so as to understand purely the variance in LOD_{ti} required. From here this could then be used to inform how geometric objects may need to be subdivided.

Figure 3 notes that predominantly responders sought the example tasks to be visualised in the 4D simulation on a daily basis aligning with the results discussed above.

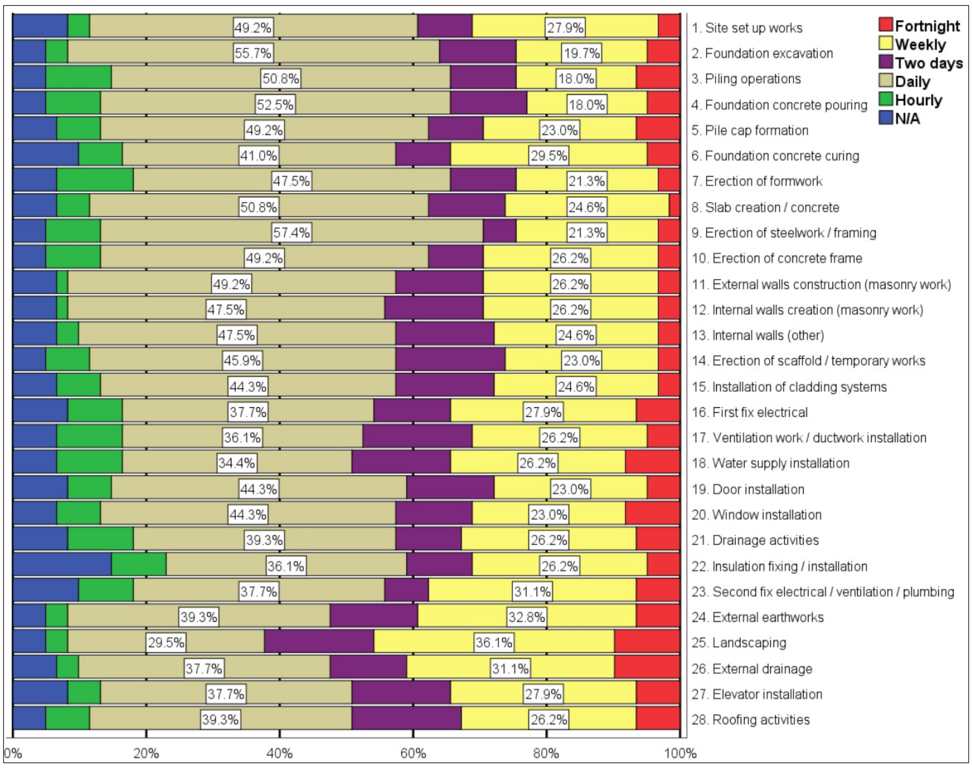

Figure 3: LOD_{ti} in 4D simulations for nominal construction tasks

Whilst this was the most frequent response for all of the nominal tasks, there was also appetite for tasks to be viewed using a range of LOD_{ti}. The majority was either daily or weekly, however there were some instances activities such as piling, formwork and ductwork installation had higher instances of those believing that hourly changes would be beneficial to see. These activities are deemed to be highly dynamic in nature and are also often the cause of time space conflicts during the construction process (Kang *et al.*, 2012; Wu and Chiu, 2010).

Cross referencing these results against the roles of the responders demonstrates that the BIM coordinators generally prefer to view the progress in the 4D simulation on a daily basis and this is mirrored by the project planners and project managers, with some exceptions and anomalies noted above. However, the lead designers lean more towards seeing progress on a weekly basis. This also correlates to the potential use that each of these particular groups sees as the potential main use of the 4D simulation. With planners and mangers seeing the use of the simulation to support construction work and the designers seeing benefits of the simulation as a more communication tool, particularly for clients.

5. DISCUSSION

The purpose of the survey was to assist in an ongoing piece of research to develop a holistic framework and subsequent methodology for the standardised approach to specify the Level of Detail for 4D simulations (LOD_{4d}). Initially a conceptual framework was derived (Figure 4) which bought together the key elements of current approaches to 4D simulation and some of the key issues that would impact on the development of the LOD of 4D simulations (adapted from Butkovic and Heesom, 2017).

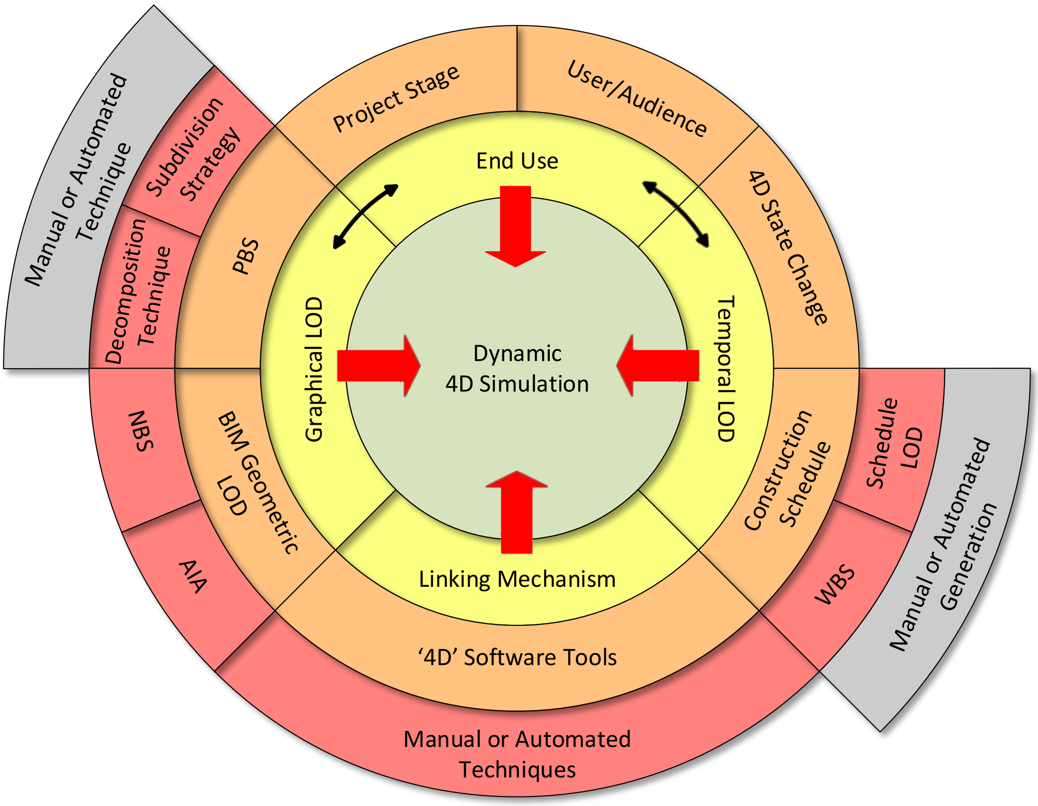

Figure 4: Conceptual Framework for dynamic 4D simulations
(Source: adapted from Butkovic and Heesom, 2017)

The framework identified 4D primary factors which impact the development of a dynamic LOD_{4d} simulations. The *End Use* of the simulation will impact the LOD_{4d} and this can be reflected by the stage of the project and the user of the simulation. For example, early concept stage simulations would potentially require less detail and may be shown as part of the planning approval. Later stage simulations may be used by the contracting team and require more detail. The *Temporal LOD* encompasses the temporal stage change of the simulation and the breakdown/detail of the construction schedule. The amount of detail in the construction schedule can impact this directly. Whilst the construction schedule is generally developed by the construction planner at various stages of the project, there are examples of work, such as Faghihi et al. (2014) which investigates the application of automated generation of schedules and this is something that could impact the LOD_{ti} development of 4D in the future. The *Graphical LOD* will encompass the amount of detail contained within the geometry of the BIM aligning to prevailing standards such as the AIA LOD in the USA and the NBS LOD approaches in the UK. The geometric breakdown of the product breakdown structure for a 4D simulation is based on how the elements are decomposed and the strategy used to do this. This is often a factor of the construction approach adopted by the planner. Generally this is undertaken manually either within the 4D tool, or as part of the BIM creation in the authoring software, however there have been examples of approaches (Heesom, 2006) where this is undertaken using a more automated approach. The *Linking Mechanism* relates to the existing technology solutions which provide the ability to link the graphical data and schedule information.

The data received from the questionnaire survey was comprised of a range of professionals who were categorised into those whose specialism was BIM, those who were designers, project planner/management and surveyors. This gave a cross section of those who currently utilise 4D BIM for a range of applications. It is becoming clear from the results of this survey that the development of 4D models is falling under the remit of the BIM specialists more than the construction planner. This itself is worthy of note, as from the early days of 4D development, it was hailed as a tool to support construction planning and specifically the construction planner. In order to produce a 4D simulation that contains the appropriate level of detail input would be needed from the construction planner and the construction management team to specify the LOD_{ti} and, if the geometry is to be divided or grouped to give a more realistic simulation, then a construction strategy/methodology would be required to support updates to the 3D geometry. It may be possible in the future to automate some of these processes with the advances in AI and build upon some of the early work on construction strategies and zoning.

The ability to generate more ‘realistic’ simulations of the construction process is controlled by the ability to a) view realistic graphical representations of individual objects during construction and b) better control the time between state changes of the 4D model (LOD_{ti}) which then has an impact on how individual geometric objects from the BIM are subdivided. The graphical LOD of the BIM objects in the design model will play a part in governing the representation of single objects in the 4D simulation. However, some previous work has identified that for the purposes of site logistics planning and management, a low LOD of geometric objects is adequate (North *et al*., 2003). The overwhelming response from the questionnaire noted that the ability to subdivide the geometry to show a more granular level of progress in the 4D simulation was beneficial. Linking this to a schedule with a higher level of detail will then provide a more detailed 4D simulation which, from the results, planners see as beneficial during logistics planning of site operations.

Some work has previously noted that the current use of 4D is actually a visualisation tool to review the already developed construction plan rather than a tool used within the planning process (Zhou *et al.*, 2009) and these results may corroborate this theory but further work is needed in this regard. The range of software tools to support the development of 4D is still limited, primarily down to the very specific nature of the task and the uses of 4D at the present time are still very much focused on the communication to various stakeholders in the construction process. This is still a significant benefit, however it appears that the opportunity to move beyond this usage into the application for detailed briefing, site logistics management and interactive project planning is yet to be realised and as this moves forward, it will become necessary to specify the LOD of the 4D simulation in the same way that the LOD and LOI are specified for models in the BIM process.

It is based on the above and building on the initial conceptual framework, that the wider remit of this work proposes to create a new framework to support the specification of the LOD of 4D simulations (Figure 5). The overall 4D LOD (LOD_{4d}) is a unification of Level of Graphical Detail (LOD_g) and the Level of Temporal Detail (LOD_{ti}) which details the time required in the simulation between state changes. However, the graphical LOD should be a combination of the detail of the geometry representing the final product (i.e. the BIM LOD - LOD_{geom}) and the Level of Detail of granularity (LOD_{gran}), which depicts how the object should be decomposed during the linking process.

It is also noted that temporary works are also now becoming a key factor in the use of 4D for more effective construction planning. Whilst Cassano and Trani (2017) discuss the level of geometric detail of temporary works elements when included in a BIM authoring tool, work such Kim and Cho (2015) or Cheng and Chang (2018) detail how temporary structures or temporary laydown areas can be included in the 4D simulation to provide a more robust and realistic view of the construction simulation. Furthermore, several of the commercial 4D tools available, such as Navisworks and Synchro, provide the ability to animate objects within the 4D simulation and this is being used to highlight route paths of plant or turning envelopes of cranes. Very often, this serves as a more aesthetic purpose to provide a level of graphical ‘realism’ to the simulation, however it is noted that in Autodesk Navisworks the ability exists to detect clashes between animated objects in a 4D environment. The results of the survey undertaken in this study do highlight there is more limited appetite for the use of state changes and LOD_{ti} on an hourly basis which may be most suited to the animation of plant objects. However, this is something that could be included as part of the granularity LOD_{gran} aspect of the LOD_g specification and as such the framework highlights the issue of temporary works and how this is fed into the 4D simulation. Often these construction/erection and deconstruction of objects associated with temporary works are additional to the BIM geometry and so also need to be considered. This will require specifying the geometric detail of any objects and also the granularity of the geometry as it is being constructed - for example the erection of scaffolding over several days. The inclusion of temporary works may also require the addition of tasks into the schedule to facilitate the development of 4D objects.

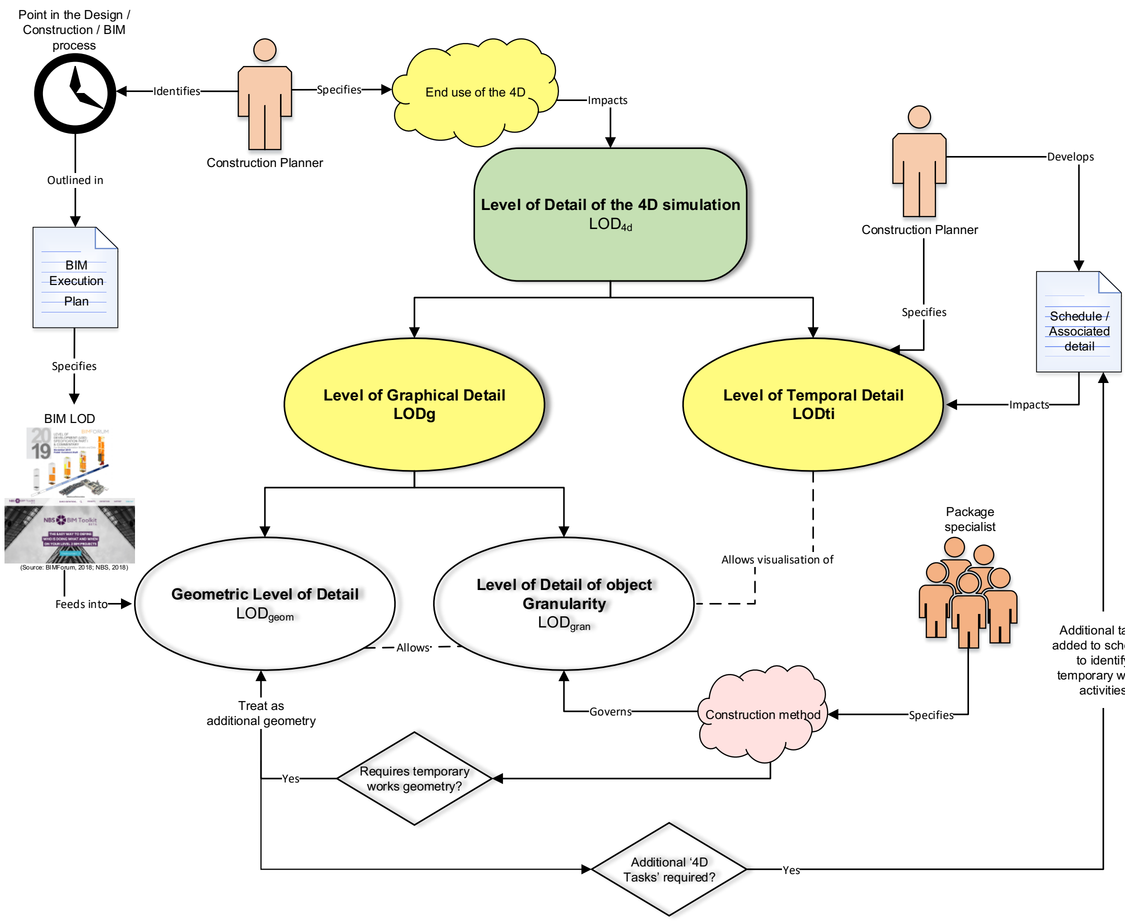

Figure 5: Framework for specifying the LOD of a 4D simulation (LOD_{4d})

5.1 Framework application

Building on the framework, the findings from literature and the results of the questionnaire a LOD_{4d} schematic is proposed to provide initial guidance on how each of the constituent LOD factors link and inform some example use cases (Figure 6). There are a range of factors that can influence the level of detail including the schedule detail, the time between state changes and the detail of the geometry which can then be granulated. Results show that 4D is currently used significantly for client briefings and marketing often this will require a low level of temporal detail with some high graphic content to ‘sell’ the scheme. As a further example, where 4D is used for workspace planning and logistics a highly detailed schedule can be used, linked with a detailed BIM model which can then be subdivided further and visualised using a high level of temporal detail.

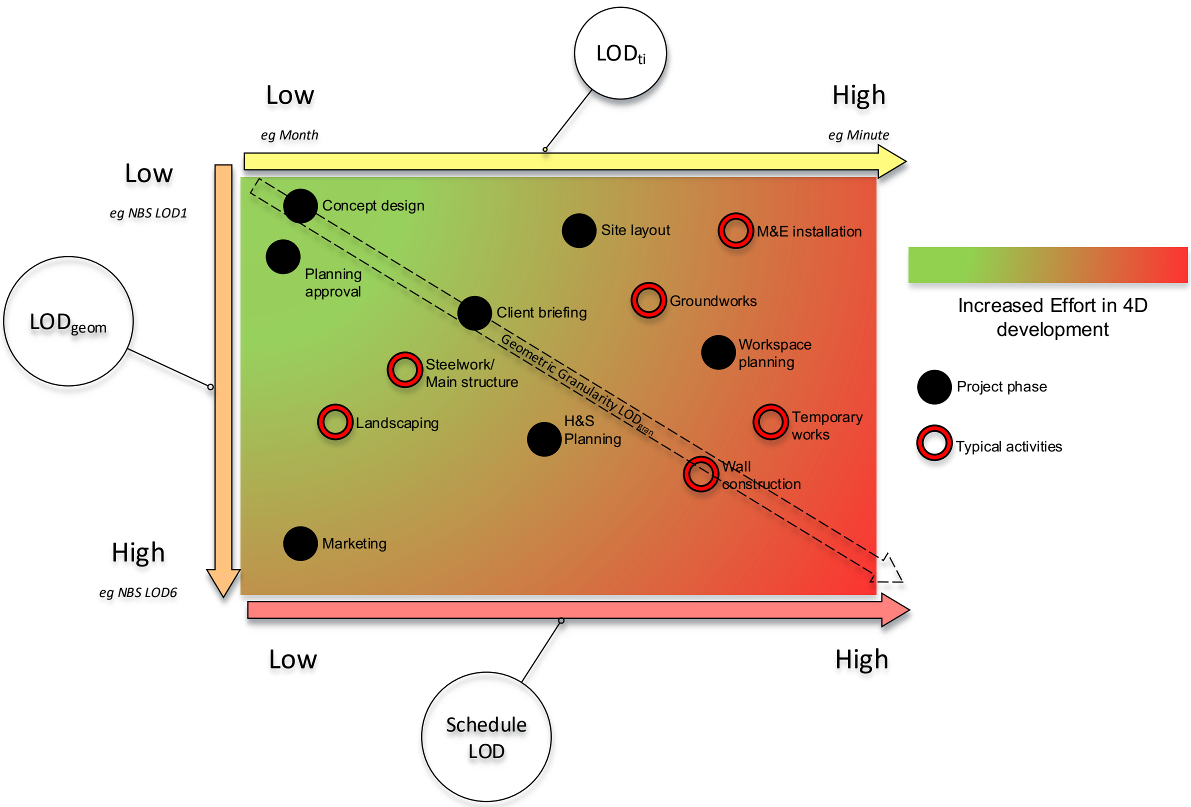

Figure 6: LOD$_{4d}$ schematic and use cases

By providing the ability to begin to specify the LOD of a 4D simulation, the potential now exists to configure the simulation for a specific purpose. In much the same way as the BIM process can now begin to specify the LOD and LOI tailored to the use of the model and the data required by the client, so the 4D simulation can be tailored to suit the project and / or specific work packages within the project. This will remove the 'one size fits all' approach of many current 4D simulations and move to support the notion reported above from questionnaire responses, which highlighted the benefit of being able to change the LOD within the 4D model during the process.

Whilst 4D is often seen as a tool for the main contractor and to manage site activities, it also needs buy in from the sub-contractors to ensure that the graphical and temporal information is available to meet the needs. The effective development of a 4D model encompasses the geometric models of the designers, main contractors and the specialist sub-contractors. In addition, the schedule for each of the work packages is required at a relevant level of detail. It is for this reason that it proposed that the issue of 4D data requirements for each stage of the project is included as part of the BIM execution plan for the project. In alignment with PAS1192-2 (BSI, 2013) the BEP highlights the data structure and requirement for each stage of the project and this can now include issues around LOD$_{4d}$. To ensure the correct data is available, an addendum to the BEP specifically focused on 4D requirements is proposed as future work, based on the outcomes of this study. This will provide a LOD$_{4d}$ matrix, similar to the Model Production Delivery Table (MPDT) utilised in the UK BIM Level 2 standards.

As noted in Figure 6, the effort required to produce higher LOD$_{4d}$ simulations is increased. Noting some of the examples provided, it is also postulated that higher LOD$_{4d}$ may only be required for certain operations, workpackages or certain periods of time throughout the project period. For example, a confined area which requires several contractors to work together (such as M&E and finishes) may require a higher LOD$_{4d}$ but only for a short period. The period immediately prior to and following this may be serviced with a lower LOD$_{4d}$. In these circumstances, it would be beneficial to have the ability in the simulation to have multi-LOD and associated data such that a single 4D simulation can run using multiple LODs throughout. The ability to move between LOD$_{ti}$ and LOD$_{gran}$ within a 4D simulation is required to be seamless. At the present this would have to be undertaken by stopping and reconfiguring the simulation for a certain period. This is a current technical limitation of the software tools available. This 'federated 4D simulation' would mean that detailed information would be required as specified in the BEP to support the project requirements. To further the concept, and building upon the collaborative nature of BIM, the development of the LOD for project could be undertaken in a multi-disciplinary collaborative environment. The work of Zhou et al. (2010) and Zhou et al. (2014) developed the philosophy of collaborative 4D development and this approach could support the generation of LOD_{4d} requirements at different stages of the project.

With the above in mind, the critical issue of cost features in the development of 4D simulations with varying LOD. The return on investment of utilising BIM is a complex area and it is difficult to derive an exact metric (Azhar, 2011). The lack of a definitive return on investment has been identified as a key barrier to the uptake of BIM (Kim et al., 2016) whilst Ahmed et al. (2014) noted that specifically a lack of real world understanding of ROI of 4D was also hampering the uptake. Ghaffarianhoseini et al. (2017) noted the benefit of BIM in reducing schedule based delays in construction, the study proposed that much further work was needed to actually derive an exact ROI. The issue of return on investment is critical when discussing the issue of LOD of a 4D simulation. As postulated in Figure 6, as the constituent parts of the LOD_{4d} increase, so does the effort required to generate the 4D simulation. This subsequently has an impact on the amount of time and the cost in developing a 4D simulation with a higher LOD. Noting that some studies have purported ROI of using BIM of significant values (Giel and Issa, 2011) there have been no substantial metrics to measure the same for 4D and specifically with the focus being on the ROI associated with the LOD of the 4D simulation. Relating this to the issue of the amount of effort required to produce a higher level LOD_{4d}, the issue of cost also supports the notion of only developing higher LOD simulations when it is required rather than a blanket approach for the entire project. These issues are proposed as an area of future work that will align to the work reported here to give a clearer indication of the value proposition associated with higher LOD_{4d}.

6. CONCLUSIONS AND FUTURE WORK

This paper has provided further detail on the issue of Level of Detail of 4D simulations, which hitherto has been an area with a paucity of research. Level of detail of 4D is a complex subject as it relates to a number of factors including the level of geometric detail, the level of detail of the temporal state change within the simulation and the potential use of the simulation which can govern how dynamic and realistic the simulation should be. The lack of research and standardised frameworks in this area has lead to simulations often defaulting to one single temporal LOD throughout a project and limited use of the ability to change the granularity of the geometry to match the needs of the end use. This work has presented an initial framework and schematic to support this backed up by the results of a survey of industry professionals who utilise 4D on real construction projects. At the moment the development of a 4D simulation can be seen as an asynchronous process, however the framework proposed here goes someway to resolve this issue.

Further work will see this framework being developed into a proposed 4D LOD specification for a construction project, to sit alongside the BIM execution plan (BEP) of a project in order to provide a more formalised use of 4D simulations. This will provide a LOD_{4d} matrix similar to the Model Production Delivery Table (MPDT) utilised in the UK BIM Level 2 standards. Additionally, work will seek to address the technological methodologies to combine multiple LOD_{gran} and LOD_{ti} within a single simulation environment to allow multiple LOD_{4d} to occur within a single project 4D simulation. At present some 4D software tools allow the decomposition of geometric objects within the creation environment, by allowing the subdivision of geometry but this is still a very manual exercise and not dynamically linked to the specification of a LOD_{ti}. The ability to do this without the need to created numerous additional tasks will further support the creation of dynamic multi-LOD 4D simulations.

REFERENCES

AACE International (2010) *AAEC International recommended practice No. 37R-06 Schedule levels of detail as applied in engineering procurement and construction* [online]. [Accessed 19 August 2018]. Available at https://web.aacei.org/docs/default-source/toc/toc_37r-06.pdf

Ahmed, S.M., Emam, H.H. and Farrell, P.E.T.E.R., 2014, December. Barriers to BIM/4D implementation in Qatar. In The 1st International Conference of CIB Middle East & North Africa Conference, Abu Dhabi, UAE (pp. 533-547).

Azhar, S., 2011. Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), pp.241-252.

Aouad, G., Lee, A., Wu, S. and Onyenobi, T. (2012) *Computer Aided Design Guide for Architecture, Engineering and Construction.* New York: Spon Press

Bedrick, J. (2013) *A Level of Development Specification for BIM Processes* [blog entry]. [Accessed 16 November 2015]. Available at: <http://www.aecbytes.com/>

BSI. (2013) *Specification for information management for the capital/delivery phase of construction projects using building information modelling* [online]. [Accessed 20 July 2018]. Available at <https://www.bimhealth.co.uk/uploads/pdfs/PAS_1192_2_2013.pdf>

Boton, C., Kubicki, S. and Halin, G. (2015a) The challenge of level of development in 4D/BIM simulation across AEC project lifecycle. A case study, *Procedia Engineering*, **123**, pp.59-67

Boton, C., Kubicki, S. and Halin, G. (2015b) 4D/BIM simulation for pre-construction and construction scheduling. Multiple levels of development within a single case study. *Creative Construction Conference 2015*, Krakow, Poland, 21-24 June, pp.500-505

Butkovic, B. and Heesom, D. (2017) Towards A Framework For Multi-LOD 4D BIM Simulations. *International Research Conference 2017*. University of Salford, 11-12 September, pp. 578-586

Cassano, M. and Trani, M.L., 2017. LOD standardization for construction site elements. Procedia Engineering, 196, pp.1057-1064.

Cheng, M.Y. and Chang, N.W., 2018. Dynamic construction material layout planning optimization model by integrating 4D BIM. Engineering with Computers, pp.1-18.

Faloughi, M. (2017) *Level of Development for 4D Project Management* [blog entry]. [Accessed 3 August 2018]. Available at: https://www.synchroltd.com/

Faghihi, V., Reinschmidt, K.F. and Kang, J.H., 2014. Construction scheduling using genetic algorithm based on building information model. Expert Systems with Applications, 41(16), pp.7565-7578.

Ghaffarianhoseini, A., Tookey, J., Ghaffarianhoseini, A., Naismith, N., Azhar, S., Efimova, O. and Raahemifar, K., 2017. Building Information Modelling (BIM) uptake: Clear benefits, understanding its implementation, risks and challenges. Renewable and Sustainable Energy Reviews, 75, pp.1046-1053.

Giel, B.K. and Issa, R.R., 2011. Return on investment analysis of using building information modeling in construction. Journal of Computing in Civil Engineering, 27(5), pp.511-521.

Gledson, B (2015) Investigating the diffusion of 4D BIM innovation In: Raidén, A B and AboagyeNimo, E (Eds) *Procs 31st Annual ARCOM Conference*, 7-9 September 2015, Lincoln, UK, Association of Researchers in Construction Management, 641-650

Gledson B. and Greenwood D.J. (2016) Surveying the extend and use of 4D BIM in the UK, ITcon Vol. 21, Special Issue Technology Strategies for Collaborative Working, pp. 57-71, https://www.itcon.org/paper/2016/4

Grytting, I., Svalestuen, F., Lohne, J., Sommerseth, H., Augdal, S. and Lædre, O. (2017) Use of LoD decision plan in BIM-projects, *Procedia Engineering*, **196**, pp.407-414

Guevremont, M. and Hammad, A. (2018) Multi-LOD 4D Simulation in Phased Rehabilitation Projects. *Proceedings of the 17th International Conference on Computing in Civil and Building Engineering (ICCCBE)*, Tampere, Finland, pp.724-731

Hamada, H.M., Haron, A.T., Zahrizan, Z.Z. and Humada, A.M. (2017) Implementation of 4D/BIM in the Iraqi construction industry. *International Journal of Engineering Systems Modelling and Simulations (IJESMS)*, **9**(4)

Han, K.K. and Golparvar-Fard, M. (2015) Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs, *Automation in Construction*, **53**, pp.44-57

Heesom, D. and Mahdjoubi, L. (2003) A Dynamic VR System For Visualizing Construction Space Usage. ASCE Construction Research Congress, Winds of Change: Integration and Innovation of Construction. Eds Molenaar, K. and Chinowsky, P. Honolulu, Hawaii. March 19-21 2003. ISBN: 0-7844-0671-5

Heesom, D. (2006) *Interactive Generation of 'Multi-Level of Detail' 4D CAD Simulation: 6th International Conference on Construction*. Application of Virtually Reality, Orlando, Florida, August 2006

Humphreys, K. (1991) *Jelen's cost and optimization engineering*. 3rd ed West Sussex: Wiley

Kang, L., Pyeon, J., Moon, H., Kim, C. and Kang, M., (2012) Development of Improved 4D CAD System for Horizontal Works in Civil Engineering Projects. *Journal of Computing in Civil Engineering*, **27**(3), pp.212-230.

Kensek, K.M. (2014) *Building Information Modeling*. New York: Routledge

Kim, K.P., Ma, T., Baryah, A.S., Zhang, C. and Hui, K.M., 2016. Investigation of readiness for 4D and 5D BIM adoption in the Australian construction industry.

Kim, K. and Cho, Y., 2015. BIM-based planning of temporary structures for construction safety. In Computing in Civil Engineering 2015 (pp. 436-444).

Kim, K., Cho, Y. and Zhang, S. (2016) Integrating work sequences and temporary structures into safety planning: Automated scaffolding-related safety hazard identification and prevention in BIM, *Automation in Construction*, **70**, pp.128-142

Kriphal, M. and Grilo, A. (2012) Compatibility between design and construction building information models, *ECPPM Proceedings*, pp.447-452

Liu, Y. and Li, S. (2013) Research on Virtual Construction in the Construction Phase and Its 4D LOD Analysis, *International Conference on Construction and Real Estate Management 2013 (ICCREM 2013)*, pp.289-297

McGeorge, D. and Zou, P. (2013) *Construction Management: New Directions*. 3rd ed. West Sussex: Wiley

McKinney, K. and Fischer, M. (1998) Generating, Evaluating and visualization Construction Schedules with CAD tools, *Automation in Construction*, **7**, pp.443-447

Mordue, S., Swaddle, P. and Philp, D. (2016) *Building Information Modeling for Dummies*. West Sussex: Wiley

NBS. (2015) *NBS BIM Toolkit* [online]. [Accessed 20 July 2018]. Available at <https://toolkit.thenbs.com/>

NBS. (2018) *The National BIM Report 2018* [online]. [Accessed 1 August 2018]. Available at <https://www.thenbs.com/knowledge/the-national-bim-report-2018>

North, S., Winch, G.M., Dawood, N., Heesom, D., Kelsey, J., Sriprasert, E. and Mallasi, Z. (2003) *Technical Evaluation: VIRCON Task 12 Report*, Manchester Centre for Civil and Construction Engineering UMIST, a VIRCON report

Romigh, A., Kim, J. and Sattineni, A. (2017). 4D Scheduling: A Visualization Tool for Construction Field Operations, *53rd ASC Annual International Conference Proceedings,* pp.395-404

Sigalov, K. and Konig, M. (2017) Recognition of process patterns for BIM-based construction schedules, *Automation in Construction*, **33**, pp.456-472

Tolmer, C.E., Castaing, C., Morand, D. and Diab, Y. (2015) Information management for linear infrastructure projects: conceptual model integrating Level of Detail and Level of Development: *Proc. of the 32nd CIB W78 Conference*. University of Technology, Eindhoven 27-29 October. Rotterdam: International Council for Research and Innovation in Building and Construction, pp.735-743

Tolmer, C.E., Castaing, C., Diab, Y. and Morand, D. (2017) Adapting LOD definition to meet BIM uses requirements and data modeling for linear infrastructures projects: using system and requirement engineering, *Visualization in Engineering*, **5**(21), pp.1-18

Trani, M.L., Cassano, M., Todaro, D. and Bossi, B. (2015) BIM level of detail for construction site design. A case study, *Procedia Engineering*, **123**, pp.581-589

Trebbe, M., Hartmann, T. and Andre, A. (2015) 4D CAD models to support the coordination of construction activities between contractors, *Advanced Engineering Informatics*, **49**, pp.83-91

Tulke, J., Nour, M. and Beucke, K. (2008) Decomposition of BIM objects for scheduling and 4D simulation, *In Proceedings of the 7th European Conference on Product and Process Modelling in the Building and related Industries*, Sophia Antipolice, France, pp. 653-660

Umar, U. A., Shafiq, N., Malakahmad, A., Nurudin, M. F., Khamidi, M. F., Farhan, S. A. and Gardezi, S. S. S. (2015) 4D BIM application in AEC industry: impact on integrated project delivery. *Research Journal of Applied Sciences, Engineering and Technology*, **10**(5), pp. 547-552

Winch, G.M. (2010) *Managing Construction Projects.* 2nd ed. West Sussex: Wiley

Winch, G.M., Usmani, A. and Edkins, A. (1998) Towards Total Project Quality: A Gap Analysis Approach, *Construction Management and Economics*, **16**, pp.193-207

Wong, A.K.D., Wong, F.K.W. and Nadeem, A. (2011) Government Roles in Implementing Building Information Modelling Systems: Comparison between Hong Kong and the United States. *Construction Innovation: Information, Process, Management*, **11**

Wu, I. and Chiu, Y. (2010) 4D Workspace conflict detection and analysis system. *In Proceedings of the 10th International Conference on Construction Applications of Virtual Reality*.

Zhou, W., Heesom, D., Georgakis, P., Nwagboso, C. and Feng, A. (2009) An interactive approach to collaborative 4D construction planning, ITcon Vol. 14, Special Issue Technology Strategies for Collaborative Working, pp. 30-47, http://www.itcon.org/cgi-bin/works/Show?2009_05

Zhou, W., Heesom, D., Georgakis, P. and HM Tah, J., 2014. User-centred design for collaborative 4D modelling. Construction Innovation, 14(4), pp.493-517.